Organometallic Vapor Phase Epitaxy Technical Program

In-Situ Monitoring and Characterization

Monday AM Room: St. Tropez/Monte Carlo/Riviera
March 12, 2001 Location: Hilton San Diego Resort

Session Chair: Tom Kuech

8:10 AM Welcome

8:20 AM
Emissivity-Correcting Pyrometry for OMVPE Applications: *William G. Breiland*[1]; Larry A. Bruskas[1]; Andrew A. Allerman[1]; Terry W. Hargett[1]; [1]Sandia National Laboratories, Dept. 1126 MS 0601, PO Box 5800, Albuquerque, NM 87185 USA

Single-wavelength emissivity-correcting pyrometry is a well-known method for remote surface temperature measurement. It is ideally suited for semiconductor deposition applications where the emissivity undergoes large changes due to thin film interference effects. However, in MOCVD applications, the method is vulnerable to significant artifacts in the temperature from reflectance drift and scaling errors and stray thermal emission from sources other than wafers. Temperature errors approaching 50 degrees can be incurred when the reflectance of the wafer exceeds 80%. We present a simple method for in situ calibration that is used to determine a single empirical parameter that corrects for all the above mentioned artifacts. This parameter is used in a slightly modified pyrometer algorithm to make artifact-free in situ surface temperature measurements during growth with 1 to 2 degree precision. Applications of this method to temperature-sensitive materials growth systems such as AlGaInN alloys are also presented.

8:40 AM
In-Situ Monitoring of the Growth of Thick Bi2Te3 and Sb2Te3 Films and Bi2Te3-Sb2Te3 Superlattices Using Spectroscopic Ellipsometry: Ishwara Bhat[1]; *Hao Cui*[1]; Rama Venkatasubramanian[2]; [1]Rensselaer Polytechnic Institute, ECSE Dept., JEC 6003, Troy, NY 12180 USA; [2]Research Triangle Institute, Research Triangle Park, NC 27709 USA

In this work, we present in-situ monitoring of the growth of thick bismuth telluride (Bi2Te3) and antimony telluride (Sb2Te3) films as well as Bi2Te3-Sb2Te3 superlattice using spectroscopic ellipsometry (SE). Bi2Te3 and Sb2Te3 films were grown by metalorganic chemical vapor deposition (MOCVD) at 350ºC. A 44-wavelength ellipsometer with spectral range from 404 nm to 740 nm was used in this study. The optical constants of Bi2Te3 and Sb2Te3 at growth temperature were determined by fitting a model to the extracted in-situ SE data of optically thick Bi2Te3 and Sb2Te3 films. Compared to the optical constants of Bi2Te3 and Sb2Te3 at room temperature[1], significant temperature dependence is observed. Using their optical constant at the growth temperature, the growth of thick Bi2Te3 and Sb2Te3 films were monitored and modeled and excellent fit between the experimental data and data generated from the best-fit model was obtained. The growth rates were determined to be 2.48 Å/sec and 1.92Å/sec for Bi2Te3 and Sb2Te3, respectively. Growth of different Bi2Te3-Sb2Te3 superlattices was also monitored. The growth of Bi2Te3 and Sb2Te3 layers can be separately seen clearly in in-situ SE data. Modeling of in-situ superlattice growth shows layers abrupt interfaces between the two constituent films. [1]H.Cui, I. Bhat and R. Venkatasubramanian, "Optical constants of Bi2Te3 and Sb2Te3 measured using spectroscopic ellipsometry", Journal of Electronic Materials, vol. 28, pp. 1111 - 1114, (1999).

9:00 AM
In-Situ Monitor and Control of Stress during MOCVD of (Al,Ga)N: *Karen E. Waldrip*[1]; Jung Han[1]; Steven R. Lee[1]; Jeff J. Figiel[1]; Brent P. Gila[2]; Cammy R. Abernathy[2]; Viswanath Krishnamoorthy[3]; [1]Sandia National Laboratories, Chem. Proc. Sci., Dept. 1126, PO Box 5800, MS 0601, Albuquerque, NM 87185-0100 USA; [2]University of Florida, Dept. of Mats. Sci. & Eng., PO Box 116400, Gainesville, FL 32611 USA; [3]University of Florida, Major Analyt. Instrumentation Ctr., PO Box 116400, Gainesville, FL 32611 USA

The ability to produce short wavelength optoelectronic devices based on AlGaN has been severely hindered by cracking of the AlGaN layers due to growth and thermal tensile stresses in the films. We demonstrate in this talk that the use of low-temperature AlGaN interlayers is effective in reducing the coherency stress when AlGaN is grown at high temperature on GaN templates on sapphire substrates. The stress evolution during growth was monitored using an in situ wafer curvature-based stress sensor and was correlated to ex situ high resolution x-ray diffraction and cross-sectional transmission electron microscopy analysis to determine the degree of coherency in the low temperature AlGaN interlayers. For 0.9um-thick AlGaN containing 20% aluminum, we found that the initial growth stress changed from tensile to compressive as the aluminum concentration in the interlayer was increased. Study of stress evolution during AlGaN growth on (111) Si substrates will also be presented. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

9:20 AM
In-Situ Determination of GaAs Free Carrier Concentration and Temperature by Raman Spectroscopy: *James E. Maslar*[1]; Wilbur S. Hurst[1]; [1]NIST, CSTL, 100 Bureau Dr., Stop 8360, Gaithersburg, MD 20899-8360 USA

In situ Raman spectroscopy was used to measure free carrier concentration and temperature of n-type GaAs in an organometallic vapor phase epitaxy reactor at temperatures between 25 deg C and 480 deg C. Previously grown GaAs epilayers and substrates with nominal n-type doping levels between 1 x 10^{15} cm^{-3} and 6 x 10^{18} cm^{-3} were examined. Models for determination of carrier concentration from Raman spectra of GaAs at elevated temperatures were evaluated.

9:40 AM
From Single Wafer to Multi-Wafer Reactors–In-Situ Sensor Assisted Process Transfer: *Kolja Haberland*[1]; Rainer Hövel[2]; Martin Zorn[3]; Markus Weyers[3]; Jörg-Thomas Zettler[4]; Wolfgang Richter[4]; [1]LayTec Gesellschaft für in-situ und Nano-SensorikmbH, Sekr. PN 5-7, Hardenbergstr. 36, Berlin D-10623 Germany; [2]Avalon Photonics Ltd., Badenerstr. 569, Postfach, Zürich CH-8048 Switzerland; [3]Ferdinand-Braun-Institut für Höchstfrequenztechnik, Albert-Einstein-Str. 11, Berlin D-12489 Germany; [4]Technische Universität Berlin, Institut für Festkörperphysik, Sekr. PN 6-1, Hardenbergstr. 36, Berlin D-10623 Germany

In-situ sensor supported MOVPE growth has recently been demonstrated successfully in single wafer reactors on rotating samples, by accessing growth rate, composition, sample temperature and doping. This paper demonstrates how this type of combined reflectance and reflectance anisotropy (R/RAS) sensor can be adapted also to state-of-the-art planetary reactors, in order to transfer pilot processes from single wafer to production line multi-wafer environments. After sketching briefly which additional sensor features had to be added (e.g. synchronization with the complex planetary rotation) we focus on an in-situ based process transfer of an AlGaAs distributed bragg mirror from a single wafer to a planetary Aixtron reactor. In both reactor types in-situ measurements of the key parameters growth rate, composition, temperature and doping level have been performed. In case of the planetary reactor, for each wafer an individual $Al_xGa_{1-x}As$ growth rate and composition has been determined. We have also studied the influence of n- and p-doping of AlGaAs on the optical signatures and found a clear dependence of the measured signal on the doping level. This was exploited for in-situ doping level measurements in the different reactors.

10:00 AM Break

Precursors

Monday AM Room: St. Tropez/Monte Carlo/Riviera
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Session Chair: Simon Watkins

10:40 AM
Purification of Dialkylzinc Precursors Using Macrocyclic Amines: *Lesley Margaret Smith*[1]; K. M. Coward[2]; A. Steiner[2]; J. F. Bickley[2]; A. C. Jones[2]; S. Petroni[3]; [1]Epichem Limited, Power Rd., Bromborough, Wirral, Merseyside CH62 3QF UK; [2]University of Liverpool, Dept. of Chem., Liverpool L69 7ZD UK; [3]Istituto Nazionale per la Fisica della Materia (INFM), UdR Lecce, Via per Arnesano, Via per Arnesano, Lecce I-73100 Italy

Despite extensive research into the carbon doping of III-V materials, zinc is still the most widely used and versatile p-dopant, with Me2Zn and Et2Zn being most often employed as precursors. The rapid growth MOVPE as a production technology for optoelectronic III-V devices has placed increasingly stringent demands on the purity of the metalorganic precursor, with trace oxygen being a particular problem, in Al-containing layers. Trace oxygen levels can be significantly reduced by the use of the adduct Me2Zn(NEt3), but it is not possible to obtain base-free Me2Zn from this compound. However, ultra-high purity dimethylzinc and diethylzinc can be readily obtained by mild thermal dissociation of their adducts with low volatility macrocyclic tertiary amines. In this paper, the synthesis and structural characterisation of (Me2Zn)2[N4-aza crown], (Me2Zn)2[N6-aza crown] and (Et2Zn)2[N4-aza crown] are reported and their dissociation behaviour is discussed.

11:00 AM
On the Suitability of Getter Purified Hydrogen for the LP-MOVPE of AlGaAs: A Comparison to Pd-Diffused Hydrogen: *Hilde Hardtdegen*[1]; R. Schmidt[1]; K. Wirtz[1]; Sara Guadagnuolo[2]; Giorgio Vergani[2]; [1]Juelich Research Center, Inst. of Thin Film & Ion Tech., Juelich D-52425 Germany; [2]Saes Getters SpA, Pure Gas R&D Labs., viale Italia 77, Lainate 20020 Italy

Diffusion through a very thin Pd foil is a well-accepted method for the purification of hydrogen carrier gas in MOVPE. However, due to the foil's mechanical fragility pinholes and cracks can form, which may go unnoticed until damage is done to the metalorganic source compounds as well as to the deposited layers resulting in high costs for production. Therefore purifying methods such as getter columns, which will chemically bind the impurities irreversibly and hold them back are a welcome alternative to Pd diffusion. The aim of this work is to test the suitability of getter purified hydrogen carrier gas for MOVPE by depositing an extremely sensitive material towards the most harmful impurity oxygen: Al0.3 Ga0.7As. Two sets of samples were grown under different deposition conditions using both purification techniques for hydrogen carrier gas. Optical and electrical characteristics for both sets of samples are comparable and will be presented. The results demonstrate the suitability of the getter technique as a true alternative for hydrogen carrier gas purification.

11:20 AM
Comparison of TMI Chemical Analysis with InP and AlInAs Film Properties: *Michael L. Timmons*[1]; Deo V. Shenai[1]; Alexandre Efimov[2]; Edward D. Gagnon[3]; [1]Rohm and Haas Company, Metalorganics, 60 Willow St., North Andover, MA 01845 USA; [2]Shiva Technologies, Inc., 6707 Brooklawn Pkwy., Syracuse, NY 13211 USA; [3]Bandwidth Semiconductor, LLC, 40 Wiggins Ave., Bedford, MA 01730 USA

Quality of organometallic sources, for example, trimethylindium (TMI), has improved significantly in recent years. Impurity levels are in part-per-billion (ppb) ranges from most metalorganics vendors. Analytical capabilities are pushed to identify and quantify impurities accurately at these levels. GDMS (glow discharge mass spectroscopy), a high-vacuum chemical analysis, allows detection of impurities at low ppb levels in grown films. A question for OMVPE chemistry becomes the following: At what level do impurities fail to make an impact on devices? To address this question, we present data that combine source chemical analysis with GDMS to show the impurity profiles in grown InP and AlInAs films. These results are compared to electrical characterization of the same films to show the impact of impurities on performance. These data show only weak cor-relation, suggesting that source quality has attained levels where little impact on devices is expected. Consistency becomes the dominant issue for source chemical manufacturers.

11:40 AM
Ammonia Gas: Purification Media Characterization by Trace Level Analysis of O2 and H2O Contamination: *Sara Guadagnuolo*[1]; Giorgio Vergani[1]; Marco Succi[1]; [1]Saes Getters SpA, Pure Gas R&D Labs., viale Italia 77, Lainate 20020 Italy

Brightness and quality of blue LED devices, and in general of most III-V compound devices, is now known to have a strong dependence on the presence of deep states. The presence of dopant species in the epilayer broadens the light emission peak due to unwanted carrier recombination effects. The intensity and width of room temperature PL spectra of GaN (for example) has been shown to increase as layer contamination is increased. A purification media for Ammonia gas, commonly used as a Nitrogen source, has been developed for the reduction and control of gaseous contamination. In this work we will illustrate some characterization studies performed of the material and some further studies we are currently performing. Trace level moisture and oxygen analyses of purified ammonia are a routine characterization procedure for us and the analytical methods for these impurities will be illustrated. Typical purification media efficiency and capacity tests will also be illustrated.

Growth Mechanisms I

Monday PM Room: St. Tropez/Monte Carlo/Riviera
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Session Chairs: Jerry Stringfellow; Nigel Mason

7:00 PM
Alternative Gas Phase Reactions During GaN Growth: Ramchandra Wate[1]; James A. Dumesic[1]; *Thomas F. Kuech*[1]; [1]University of Wisconsin, Dept. of Chem. Eng., 1415 Engineering Dr., Madison, WI 53706 USA

The metalorganic vapor phase epitaxy of GaN is complicated by the extensive and pervasive complex gas phase chemistry within the growth system not typically found in the metal organic vapor phase epitaxy of other III-V materials. The most well known reaction is the formation of a gas phase adduct between trimethyl gallium, $(CH_3)_3Ga$, and ammonia, NH_3, that leads to the formation of more complex gas phase products, such as $((CH_3)_2GaNH_2)_{x=2 \text{ or } 3}$, which further react and complicate the detailed growth behavior. The detailed mechanisms responsible for the observed gas phase reactions were investigated by density functional theory (DFT) calculations, performed with Gaussian98 software. These calculations initially determined the heat of reaction for the overall reaction as well as the elementary steps. The pathway where a second ammonia molecule acts as a hydrogen transfer agent is the most favorable one among the three pathways examined.

7:20 PM

A Study of Gas Phase Reactions in TMGa-NH3-NH2 Using In-Situ Raman Spectroscopy: *Min Huang*[1]; Jang Yeon Hwang[1]; Timothy J. Anderson[1]; [1]University of Florida, Chem. Eng. Dept., Gainesville, FL 32611 USA

The most common precurs for MOCVD of GaN are Trimethylgallium (TMGa) and ammonia (NH3). It is well known that TMGa and NH3 form a TMGa:NH3 adduct at low temperature. It is suggested that at the higher temperature region close to the substrate, this adduct decomposes to yield the dimer or trimer of an addcut species ((CH3)2GaNH2)x. In this contribution, the gas phase thermal dissociation/decomposition of TMGa:NH3 in N2 has been studied at typical MOCVD reaction conditions by in situ Raman spectroscopy. Besides the formation of((CH3)2GaNH2)x species, at 3.7 mm from the substrate temperature above 530 K, dissociation of the parent adduct TMGa:NH3 was observed to produce TMGa. The reactions were probed in a vertical impinging flow cylindrical MOCVD reactor. Gas phase temperature profiles were also obtained simultaneously using N2 rotational spectra. A gas phase reaction mechanism scheme is proposed based on the downstream spatially resolved Raman observation.

7:40 PM

Low Temperature Nitride Precursor Reactions: *J. Randall Creighton*[1]; [1]Sandia National Laboratories, Dept. 1126, PO Box 5800, MS-0601, Albuquerque, NM 87185 USA

We have the examined the reactions and interactions of TMAl and TMGa with ammonia using a variety of techniques. As expected, both metalorganics react with ammonia to form adducts, which we unambiguously identify with mass spectroscopy. However, over the 0-200°C range we have found no evidence supporting decomposition reactions such as methane elimination. As the temperature is raised the adducts simply dissociate back into the original reactants at rates consistent with equilibrium calculations. We have measured the vapor pressures of the adducts and their mixtures near room temperature and found that condensation can be a significant process, especially at higher reactor pressures. At 18°C the TMAl:NH3 and TMGa:NH3 vapor pressures are 75 and 410 millitorr, respectively. The two species form a nearly ideal solid solution, so the presence of one component will significantly affect the vapor pressure of the second component in a manner that mimics a "parasitic" reaction.

8:00 PM

Utilization of Results from In-Situ Vapor Phase UV-VIS Spectroscopy in the Design of Materials for OMVPE Growth: *William S. Rees*[1]; Oliver Just[1]; Bettie Obi-Johnson[2]; Jason S. Matthews[3]; [1]Georgia Institute of Technology, Sch. of Chem. & Biochem., 770 State St., Boggs Bldg., Rm. 3-44, Atlanta, GA 30332-0400 USA; [2]Celanese Acetate, 2850 Cherry Rd., Rock Hill, SC 29730 USA; [3]Union Carbide Corporation, Tech. Ctr., 3200 Kanawha Trpk., PO Box 8361, South Charleston, WV 25303-0361 USA

In OMVPE growth of oxides, an issue receiving attention is the design of appropriate precursor chemistries. One challenge in this field is to balance desirable growth mechanisms with sufficient vapor pressure and vapor phase stability of the source compounds. Relying on in situ UV-VIS spectroscopy as a vapor phase diagnostic, deposition mechanisms have been examined for a series of metal oxide precursors. The information gained in this study has been utilized in designing ligands for attachment to specific metals. This lecture will describe the in situ vapor phase UV-VIS monitoring apparatus, present selected results on decomposition mechanisms for metal oxide compositions (Y, Ba, Cu), and demonstrate the utility of including such studies in the design of molecules for OMVPE growth (Mg, Yb).

8:20 PM

Epiready GaAs Substrates for MOVPE, Differences Between On-Axis and Vicinal Substrates: *Nigel John Mason*[1]; [1]University of Oxford, Phys. Dept., Clarendon Lab., Parks Rd., Oxford, Oxon OX1 3PU UK

The preparation of substrates, for MOVPE growth is a poorly understood process. Up to now, there have been no reports of differences in preparation for on-axis and vicinal substrates. It is well known that growth on on-axis substrates is more difficult but some devices require them to be used for optimum device performance. It is therefore important to try to observe and understand any differences between the two types of substrates during the preparative stage. We observe that GaAs: Si substrates show kinetically controlled island growth [islands 50 nm high and 200 nm long, at 450°C]. Since the ambient is molecular hydrogen and the reactor is clean at the outset, the island material must be coming from incomplete sublimation from the substrate. The vicinal substrates show a completely smooth surface except for the expected offcut. Subsequent homoepitaxy results in rough morphology for on-axis substrates and smooth for vicinal. Suggestions for smooth growth on-axis will be presented.

Mid-Infrared Materials and Devices

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Session Chair: Ishwara Bhat

8:20 AM

Structural and Optical Properties of Ultrathin GaSb/GaAs Quantum Wells Grown by MOVPE: *O. J. Pitts*[1]; S. P. Watkins[1]; [1]Simon Fraser University, Dept. of Phys., 8888 University Dr., Burnaby, BC V5A 1S6 Canada

We report on the growth and characterisation of multiple type II quantum wells of GaSb of up to 2 monolayer thickness embedded in GaAs. These structures are formed by an Sb-As exchange reaction. At 500ºC, the GaSb thickness increases with the exchange exposure time, up to 10 seconds, then decreases for t>10 sec. The crystalline quality of the samples with exchange times less than 10 sec. is shown to be excellent by high-resolution x-ray diffraction, however in-situ monitoring by reflectance difference spectroscopy presents evidence for strong Sb-As intermixing. Optical properties of the GaSb quantum wells are studied by photoluminescence and photoreflectance (PR) measurements. Two strong features below the GaAs bandgap are resolved by PR, which we attribute to type-II transitions involving heavy and light holes. The splitting of these transitions is shown to increase linearly with the GaSb well thickness. These features are observed even at submonolayer GaSb coverages.

8:40 AM

Structural, Electrical, and Optical Characterization of GaAsSb on InP: *S. P. Watkins*[1]; O. J. Pitts[1]; C. Dale[1]; K. L. Kavanagh[1]; V. Fink[1]; E. Chevalier[1]; S. Hummel[2]; N. Moll[2]; [1]Simon Fraser University, Dept. of Phys., 8888 University Dr., Burnaby, BC V5A 1S6 Canada; [2]Agilent Technologies, Elec. Rsch. Lab., Palo Alto, CA USA

GaAsSb is a promising material for the fabrication of high speed InP-based double heterojunction transistors. Previous reports of low hole mobilities in GaAsSb layers grown at Simon Fraser University (SFU) suggested an unusually strong alloy scattering mechanism for this material. Recent samples grown at Agilent show somewhat higher mobilities approaching those of InGaAs at comparable doping levels. We report differences in the levels of compositional ordering observed by transmission electron microscopy in samples grown at SFU and at Agilent, and believe that this is responsible for the observed variations in hole mobilities. The ordering, detected in [001] plan-view images and selected area diffraction patterns, has a primary modulation period of around 1.1 nm aligned with a particular [110] in-plane direction. Room temperature Raman spectra show no evidence of phase separation. A strong plasmon peak observed in the Raman spectra can be used to estimate the carrier concentration at high doping levels.

9:00 AM

The Preparation of AlGaAsSb Diodes On GaSb Substrates Using Metal Organic Chemical Vapor Deposition: *Robert M. Biefeld*[1]; J. G. Cederberg[1]; G. M. Peake[1]; M. N. Palmisiano[2]; [1]Sandia National Laboratory, Dept. 1126, PO Box 5800-0601, Albuquerque, NM 87185-0601 USA; [2]Bechtel Bettis, Inc., West Mifflin, PA 15122 USA

We are exploring InGaAsSb and AlGaAsSb lattice matched to GaSb for use in thermal photovoltaics (TPV). Toward this end we have investigated the growth and doping of AlGaAsSb using metal-organic chemical vapor deposition (MOCVD) in an Emcore D75 high-speed rotating disk reactor. We have also explored the n- and p-type doping of this material using diethyltellurium, tetraethyltin, and diethylzinc. We will report on the growth conditions used to prepare these materials as well as their characterization by x-ray diffraction, atomic force microscopy, photoluminescence, secondary ion mass-spectroscopy, and Hall measurements. We are currently investigating the source of oxygen and carbon impurities in AlGaAsSb and will also report on these results. We will present current-voltage measurements of a cell isolation diode fabricated from AlGaAsSb showing a breakdown voltage of greater than -5 V at -1 amp/cm^2 and a high shunt resistance. These diodes should be able to serve as isolation diodes in TPV cells.

9:20 AM

Spontaneous Vertical Composition Modulation in Epitaxial GaInAsSb Grown on Vicinal Substrates: *Christine A. Wang*[1]; Christopher J. Vineis[1]; Daniel R. Calawa[1]; Paul M. Nitishin[1]; [1]MIT Lincoln Laboratory, Electro-Optical Matls. and Devices, 244 Wood St., Lexington, MA 02420 USA

Observations of spontaneous vertical composition modulation (VCM) in epitaxial Ga1-xInxAsySb1-y (0<x<0.2, 0<y<0.2) are reported. Nominally lattice matched layers are grown by organometallic vapor phase epitaxy on (001) GaSb substrates miscut 2 or 6° toward (-1-11)A, (1-11)B, or (101). Field emission scanning electron microscopy and transmission electron microscopy (TEM) of epilayer cross-sections reveal a layered structure with a high degree of regularity in the growth direction. The layers are continuous and straight over several microns of lateral distance, and spontaneously form a highly regular superlattice with a periodicity between 15 to 20 nm. This VCM is reproducible and is observed for a wide range of substrate miscuts, alloy compositions, and deposition temperatures (525 to 575°C). Cross-section TEM suggests that GaInAsSb self-organizes at the onset of growth and maintains a consistent periodicity throughout several microns of deposition. Triple-axis x-ray diffraction shows a particularly remarkable feature of the atoms ordering to produce a layered structure that is tilted 4° in addition to the miscut angle of the (001) substrate surface plane.

9:40 AM

Lateral Epitaxial Growth of GaSb: S. S. Yi[1]; Darren M. Hansen[1]; Brian E. Hawkins[1]; *Thomas F. Kuech*[1]; C. K. Inoki[2]; D. L. Harris[2]; T. S. Kuan[2]; [1]University of Wisconsin, Dept. of Chem. Eng., 1415 Engineering Dr., Madison, WI 53706 USA; [2]University at Albany, State University of New York, Dept. of Phys., Albany, NY 12222 USA

A principal concern in the growth of GaSb on GaAs substrates is the large, 8 % lattice mismatch which leads to a high threading dislocation density on the order of ~$10^{10}cm^{-2}$. The lateral epitaxial overgrowth (LEO) of GaSb on GaAs substrates is of particular interest because the laterally grown GaSb material could exhibit a reduced threading dislocation density. We present the successful results of LEO of GaSb on patterned GaAs substrates by metalorganic chemical vapor deposition. Transmission electron microscopy measurements show that the density of dislocations in the GaSb layer grown on a patterned GaAs substrate with sub-micron openings is less than 10^6cm^{-2}. Local stress simulation indicates that the local stress gradient near a small opening is effective in bending and confining dislocations to within ~2 µm from the growth window, resulting in significant dislocation density reduction. We are exploring InGaAsSb and AlGaAsSb lattice matched to GaSb for use in thermal photovoltaics (TPV). Toward this end we have investigated the growth and doping of AlGaAsSb using metal-organic chemical vapor deposition (MOCVD) in an Emcore D75 high-speed rotating disk reactor. We have also explored the n- and p-type doping of this material using diethyltellurium, tetraethyltin, and diethylzinc. We will report on the growth conditions used to prepare these materials as well as their characterization by x-ray diffraction, atomic force microscopy, photoluminescence, secondary ion mass-spectroscopy, and Hall measurements. We are currently investigating the source of oxygen and carbon impurities in AlGaAsSb and will also report on these results. We will present current-voltage measurements of a cell isolation diode fabricated from AlGaAsSb showing a breakdown voltage of greater than -5 V at -1 amp/cm^2 and a high shunt resistance. These diodes should be able to serve as isolation diodes in TPV cells.

10:00 AM Break

GaInAsN

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Session Chair: Raj Bhat

10:40 AM

Indium and Nitrogen Determination in (GaIn)(NAs)/GaAs Multi-Quantum Well Structures: *Kerstin Volz*[1]; Joerg Koch[1]; Falko Hoehnsdorf[1]; Andreas Schaper[1]; Wolfgang Stolz[1]; Leander Tapfer[2]; Horst Baumann[3]; [1]Philipps University Marburg, Mats. Sci. Ctr., Hans-Meerwein St., Marburg 35032 Germany; [2]P.A.S.T.I.S., CNRSM, Brindisi, Italy; [3]Johann Wolfgang Goethe University, Inst. for Nucl. Phys., Frankfurt/Main, Germany

The novel material system (GaIn)(NAs)/GaAs opens up the possibility of realizing 1.3 or even 1.55 µm wavelength emission based on GaAs substrates. This high wavelength emission is due to the large bandgap bowing of this quaternary material system. The dependence of this bowing on the In and N concentration is up to now not known in detail. Additionally, the investigated material system exhibits a large miscibility gap under thermodynamic equilibrium conditions. Therefore the exact knowledge of the composition of the material is crucial for applications. Multi-quantum well (MQW) structures of the metastable (GaIn)(NAs)/GaAs have been grown under non-equilibrium conditions by MOVPE, using as group V precursors 1,1-dimethylhydrazine and tertiarybutylarsine. (Resonant) Rutherford Backscattering Spectrometry and high-resolution Secondary Ion Mass Spectrometry have been applied to determine the In and N contents in the MQW systems. The elemental composition, which has been obtained from these investigations will be compared to the In and N contents gained from dynamical simulations to high-resolution XRD spectra. The accuracy of the individual techniques on the determination of the elemental composition will be evaluated and discussed.

11:00 AM

GaInNAs Quantum Well and Quantum Dot Structures for 1.55 µm Emission on GaAs: Teppo Eerikki Hakkarainen[1]; Juha Ilmo Toivonen[1]; Marco Ilmari Mattila[1]; Markku Antero Sopanen[1]; Harri

Lipsanen[1]; [1]Helsinki University of Technology, Optoelectronics Lab., Otakaari 7 A, Espoo 02015 Finland

GaInNAs quantum wells (QWs) and self-assembled quantum dots (QDs) may be utilized as an active media for 1.55 µm emission on GaAs. We have fabricated GaInNAs QW and QD structures by atmospheric pressure metalorganic vapor phase epitaxy (MOVPE) using dimethylhydrazine (DMHy) and tertiarybutylarsine (TBAs) as sources for nitrogen and arsenic, respectively. The effect of in-situ and post-growth annealing on the optical properties of QW samples was studied in detail. The effect of coverage and growth temperature on density, size, uniformity and optical properties of the GaInNAs islands was studied. Room temperature photoluminescence of up to 1.55 µm was obtained from the structures. Laser diode structures were fabricated and optically excited. Laser emission at 1.15 µm was observed from QW structures. The material system seems promising for the fabrication of 1.55 µm lasers on GaAs.

11:20 AM

Interface Induced Changes in the Optical Properties of (GaIn)(NAs): *Joerg Koch*[1]; Bernardette Kunert[1]; Stephan Schaefer[1]; Falko Hoehnsdorf[1]; Thorsten Torunski[1]; Siegfried Nau[1]; Kerstin Volz[1]; Wolfgang Stolz[1]; [1]Philipps University Marburg, Mats. Sci. Ctr. & Dept. of Phys., Hans-Meerwein St., Marburg 35032 Germany

(GaIn)(NAs) has attracted a lot of interest in recent years, due to the possibility to realize 1.3 µm or even 1.55 µm wavelength emission based on GaAs substrates. We have investigated in detail the influence of interface roughness on the optical as well as structural properties in (GaIn)(NAs)/GaAs multiple quantum well (MQW) structures. All samples have been deposited by MOVPE at low growth temperatures of 525°C, applying the efficiently decomposing precursors TEGa, TMIn, TBAs and UDMHy. The interfaces have been investigated by atomic force microscopy (AFM), transmission electron microscopy (TEM) studies and means of high resolution X-ray diffraction (HR-XRD). Various experiments on growth interruptions, surface stabilization and thermal annealing of the interior interfaces in metastable (GaIn)(NAs)/GaAs MQW structures have been performed to investigate the optical and structural changes. Possible correlations to device performance will be presented and discussed. Financial support by the Deutsche Forschungsgemeinschaft, Infineon Technologies and Mochem is gratefully acknowledged.

11:40 AM

Material Growth and Design of InGaAsN Solar Cells: *Andrew A. Allerman*[1]; Steve R. Kurtz[2]; Eric D. Jones[3]; Robert M. Sieg[2]; [1]Sandia National Laboratories, Dept. 1126, M/S0601, PO Box 5800, Albuquerque, NM 87185 USA; [2]Sandia National Laboratories, Dept. 1742, M/S0603, PO Box 5800, Albuquerque, NM 87185 USA; [3]Sandia National Laboratories, PO Box 5800, Dept. 1123, M/S0601, Albuquerque, NM 87185 USA

Metal-organic chemical vapor deposition has been used to grow InGaAsN solar cells with a bandgap (»1.05eV) suitable for integration with the existing InGaP/GaAs multi-junction solar cells. InGaAsN solar cells were grown to examine the effects of V/III ratio and doping on cell performance. Additional cells have been measured that employ doping and compositional grading, and other structural designs to enhance photocurrent generation. Solar cell internal quantum efficiencies (IQE) »70% and open circuit voltages (Voc) of »0.4V are obtained for material with a 1.05eV bandgap. The hole diffusion length in annealed, n-type, InGaAsN is approximately 1µm and has, to date, been independent of nitrogen concentration. Electron diffusion lengths are observed to scale with nitrogen concentration, ranging from 0.4µm in 1.20eV alloys (» 1% N) to < 0.1µm in 1.05eV alloys (» 2.5% N). To date, high quantum efficiencies have only been obtained with cell designs utilizing hole diffusion in n-type material.

Posters

Tuesday PM - 7:00 PM	Room: Pavilion
March 13, 2001	Location: Hilton San Diego Resort

Session Chairs: Bob Biefeld; Steve Hummel

Three-Minute Oral Summaries in St. Tropez/Monte Carlo/Riviera Room

Self-Organized Growth of InAs Quantum Wires on GaAs Substrate by MOCVD: *Benzhong Wang*[1]; *Soo Jin Chua*[1]; [1]Institute of Materials Research & Engineering, 3 Research Link, Singapore 117602 Singapore

Self-organized InAs quantum wires are first grown on a vicinal GaAs (001) substrate by MOCVD using TMGa, TMIn and TBA as source materials. Two-dimensional, quasi-three-dimensional of wires, and three-dimensional of islands growth processes are observed during InAs deposition at higher growth temperature. However, islands are not formed even if InAs with 6 monolayers is deposited on the substrate at 410°C. Very strong photoluminescence (10K) emitted from the sample with ~1.5 monolayer deposition is located at 874.8 nm with full width at half maximum of 13.8 meV. The emitting wavelength can be easily changed by a mount of InAs depositing.

Determination of Free Carrier Concentration in n-type GaSb Using Raman Spectroscopy: *James E. Maslar*[1]; Wilbur S. Hurst[1]; Christine A. Wang[2]; Douglas C. Oakley[2]; [1]NIST, CSTL, 100 Bureau Dr., Stop 8360, Gaithersburg, MD 20899-8360 USA; [2]MIT, Lincoln Lab., 244 Wood St., Lexington, MA 02420-9108 USA

Raman spectroscopy was used to evaluate the free carrier concentration in n-type GaSb. GaSb epilayers lattice-matched to GaSb substrates, GaSb epilayers lattice-mismatched to GaAs substrates, and GaSb substrates were examined. Epilayers were grown by organometallic vapor phase epitaxy while substrates were grown by the liquid encapsulated Czochralski method. GaSb epilayers grown on different substrates were investigated since GaSb-based device structures are grown on GaSb substrates, whereas test structures for GaSb carrier concentration measurement are grown on GaAs substrates. Different substrates are employed because electrical measurement of carrier concentration requires a semi-insulating substrate and semi-insulating GaSb is difficult to obtain. Raman spectra indicate that GaSb epilayers grown on GaSb substrates have larger free carrier concentrations than corresponding GaSb epilayers grown on GaAs substrates under nominally identical conditions. This is significant because the assumption is often made that for nominally identical growth conditions the GaSb carrier concentration is independent of substrate.

P-type Carbon Doping of GaSb: *Rodney D. Wiersma*[1]; James A. H. Stotz[1]; Oliver J. Pitts[1]; Michael L. W. Thewalt[1]; *Simon P. Watkins*[1]; [1]Simon Fraser University, Dept. of Phys., 8888 University Dr., Burnaby, BC V5A 1S6 Canada

The growth of carbon-doped GaSb by MOVPE has never been reported, to our knowledge, despite increasing interest in carbon-doped GaAsSb alloys for HBT applications.[1] An important issue is the question of how carbon affects the lattice constant of GaSb alloys at high doping levels. In this work, we report the use of carbon tetrachloride in conjunction with triethylgallium and trimethylantimony to achieve doping levels in GaSb from 1e17 to greater than 1e19 cm-3. High resolution X-ray diffraction measurements confirm that the effect of carbon on the lattice parameter is significant for doping levels above 1e19 cm-3 as in the case of GaAs. By introducing controlled low doping levels of carbon into thick homoepitaxial samples we have succeeded for the first time in identifying carbon-related low temperature photoluminescence bands, which we suggest are due to donor-acceptor pair and free-to-bound transitions of carbon acceptors. [1]C.R. Bolognesi, S.P. Watkins, Compound Semiconductor 6, 94 (2000)

Effect of Orientation on the Growth Rate and Silicon Incorporation Rate on GaSb Grown by Metalorganic Vapor Phase Epitaxy: *Ishwara B. Bhat*[1]; Jian Yu[1]; [1]Rensselaer Polytechnic Institute, ECSE Dept., JEC 6032, 110 8th St., Troy, NY 12180 USA

The incorporation rate of dopants during metalorganic vapor phase epitaxy (MOVPE) strongly depends on the orientation of the starting substrates. MOVPE of Si-doped GaSb layers grown on (100), (111)B and (111)A substrates were used to study the effect of orientation on the growth and silicon incorporation rates. Orientation dependence of growth rates and silicon incorporations were studied as a function of temperature and V/III ratio. As the V/III ratio increased, the growth rate on the (111)B oriented substrate decreased and the growth rate on the (111)A oriented substrate increased. The surface morphology on different substrates was studied by scanning electron microscopy (SEM) and atomic force microscopy (AFM). Flat-top hexagonal hillocks were observed on (111)B surface, and the growth was by step-flow on these facets. A surface kinetic growth model has been proposed to account for the growth features observed on the (111)B surfaces. Finally, the orientation dependence of silicon incorporation was studied by secondary ion mass spectrometry and Hall measurements. It was observed that the silicon incorporation rate was 4-8 times higher on (100) oriented surface than on the (111)B oriented substrate. Data from the electrical and morphological studies are presented.

Orientation Dependence of GaInAsSb Grown by Organometallic Vapor Phase Epitaxy: *Christine A. Wang*[1]; Daniel R. Calawa[1]; Christopher J. Vineis[1]; [1]MIT Lincoln Laboratory, Electro-Optical Mats. & Devices, 244 Wood St., Lexington, MA 02420-9108 USA

The GaInAsSb alloys, which are currently being developed for optoelectronic devices that operate in the mid-infrared wavelength range, are thermodynamically metastable materials and can phase separate. The phase separation proceeds during growth at the surface of the epitaxial layer and leads to degradation in material quality. Consequently, the epitaxial surface step structure, as it is affected by growth kinetics, is important in understanding approaches to further improve GaInAsSb epitaxial alloys. This paper reports the orientation dependence of GaInAsSb alloys grown by organometallic vapor phase epitaxy. Layers were grown nominally lattice matched to (001) GaSb substrates with either a 2° or 6° miscut toward (-1-11)A, (1-11)B, or (101). The surface structure was measured by ex-situ atomic force microscopy, while structural and optical properties were determined by triple axis x-ray diffraction, transmission electron microscopy, and photoluminescence. A periodic surface step structure is correlated with good structural and optical properties, while an irregular surface is indicative of phase-separated material with comparatively degraded properties. The surface decomposition is affected by substrate miscut angle, and details of the dependence of phase separation on substrate misorientation are reported.

GaAs/GaInP Uniformity Control in Planetary Reactors®: *T. Schmitt*[1]; M. Deufel[1]; J. Hofeldt[1]; *M. Heuken*[1]; H. Juergensen[1]; [1]Aixtron AG, Kackertstr 15-17, Aachen 52072 Germany

The MOCVD approach has been developed to provide material of superior quality in terms of lateral uniformity and abrupt interfaces. This will be shown on the basis of GaAs/GaInP superlattices grown on GaAs in a standard 8x4 inch configuration of an AIX 2600G3 system, which is based on a laminar radial flow. The excellent p-doping uniformity of less than 1% at a doping level of $3x10_{19}$ cm_{-3} and controllability of auto carbon doping in GaAs will be shown and discussed in detail. Here we use XRD-, sheet resistance-, Hall- and CV-profile measurements to assess the layer properties. Hereby we will show the influence of the group V gas flow on the growth rate and auto doping. In addition unique thickness uniformity below 1% standard deviation in GaInP based layer structures, which is the basic demand for the commercial production of electronic and optoelectronic devices like UHB LED, LASER and HEMT will be discussed.

Elemental Characterization of MOVPE Materials by Glow Discharge Mass Spectrometry: *Alexandre G. Efimov*[1]; *Martin Kasik*[1]; Karol Putyera[1]; Olivier Moreau[1]; [1]Shiva Technologies., Inc., 6707 Brooklawn Pkwy., Syracuse, NY 13211 USA

For a decade Glow Discharge Mass Spectrometry (GDMS) has been used routinely for the trace elemental analysis of 10-100 microns thick layers of solids. Its application to MO VPE semiconductor layers was beyond capabilities of the technique because of inherent high sputtering rates (0.1-0.3 microns/min). Advances in the technique allowed us to diminish sputtering rates down to 0.02-0.03 microns/min. At the same time detection limits were at the level below 1 x 10e14 at/cm3 for simultaneous analysis of twelve elements in A3B5 materials and films on Si grown by OM VPE. In the recent paper we demonstrate results of trace elemental characterization of 1-10 microns thick MO VPE materials (GaAlAs, InGaAs, InP and Cu/Si). GDMS has been useful for evaluation of trace elemental background in precursor materials, finding sources of contamination in epitaxial process and substrates, interface study and rough depth profiling preceded high-resolution SIMS analysis.

Implementation of Ion Implantation for III-V Compliant Substrates: *Martin Chicoine*[1]; Sjoerd Roorda[1]; Remo A. Masut[2]; Patrick Desjardins[2]; Chantal Beaudoin[1]; [1]Universite de Montreal, Dept. of Phys., C.P. 6128 Succursale Centre-Ville, Montreal, Quebec H3C 3J7 Canada; [2]Ecole Polytechnique de Montreal, Genie Physique, C.P. 6079 Succ. Centre-Ville, Montreal, Quebec H3C 3A7 Canada

A compliant substrate will allow the partition of the strain in a heteroepitaxial coherent film or heterostructure with the substrate. We propose that a shallow uniform layer of nanometer-sized cavities below the surface of the substrate will de-couple the top thin layer of the substrate, thus effectively producing a pseudo free-standing thin layer, which could render the substrate compliant. The present work shows that such cavities can be created in III-V substrates by low energy helium implantation followed by adequate thermal treatment of the substrate previous to growth. Pre-implantation, however, may create structural damage in the substrate, particularly near the surface, which seriously affects subsequent material growth. We have established conditions for the creation of cavities followed by successful OMVPE of InP-based heterostructures. These heterostructures of varying strain and thickness, and the underlying substrate were characterized structurally by high resolution X-ray diffraction and transmission electron microscopy. We will also present absorption and photoluminescence data comparing simultaneous growth on normal and pre-implanted substrates.

MOCVD-Grown InGaAsN using Efficient and Novel Precursor, Tertiarybutylhydrazine, for Optoelectronic & Electronic Device Applications: *Nein-yi Li*[1]; Paul R. Sharps[2]; Fred Newman[2]; Hong Hou[2]; Pablo Chang[3]; Albert G. Baca[4]; Ravi Kanjolia[5]; [1]Kingmax Optoelectronics, No. 1 Kuang Fu North Rd., Hsin Chu Industrial Park, Hu Kuo, Taiwan; [2]Emcore PhotoVoltaics, 10420 Research Rd. SE, Albuquerque, NM 87123 USA; [3]Agilent Technology, 3175 Bowers Ave. M. S. 87D, Santa Clara, CA 95054 USA; [4]Sandia National Laboratories, 1515 Eubank Blvd. SE, Albuquerque, NM 87185-0603 USA; [5]Epichem Inc., 26 Ward Hill Ave., Haverhill, MA 01835-0730 USA

Currently, dimethylhydrazine (DMHy) has been commonly used as the N source for InGaAsN growth by MOCVD. Generally speaking, a low-temperature growth and a much higher DMHy/AsH3 flow rate ratio are necessary to incorporate enough N into InGaAs by MOCVD. However, incomplete pyrolysis of DMHy at low growth temperatures usually introduces carbon impurities from methyl-ligand in DMHy into InGaAsN epilayers. In addition, a much higher DMHy flow is required to maintain a high flow rate ratio of DMHy/AsH3 for InGaAsN growth, making DMHy not practical and economical for low-cost mass production, especially for high-efficiency quadruple-junction InGaAsN solar cells. Therefore, we propose and demonstrate, for the first time, the feasibility of using tertiarybutylhydrazine (TBHy) as an efficient and a less carbon-containing N precursor for the growth of high-quality InGaAsN by MOCVD at lower growth temperatures. Based on our preliminary results, TBHy is a more efficient and a less carbon-containing N precursor than DMHy for growth of high-quality InGaAsN. More details on performance of InGaAsN solar cells & laser diodes will be presented.

Bulk Sub-Atmospheric Pressure Hydride Storage and Delivery System: *Karl Olander*[1]; [1]ATMI, Inc., 19616 Gulf Blvd., Ste. 301, Indian Shores, FL 33785 USA

During the last five years, the sub-atmospheric pressure storage and delivery of toxic and pyrophoric gases has evolved from supplying ion implant dopants to broader acceptance in CVD and OMVPE applications. SAGE [Sub-Atmospheric Pressure Gas Enhanced] containers that can deliver in excess of 200 pounds of arsine [450 Liter] have been approved by the DOT and are in development. Arsine purity comparable to high pressure sources has also been achieved. This paper compares conventional high pressure hydride use with bulk SAGE delivery systems in several key areas; [1] risk reduction, [2] cost to install and [3] overall cost of ownership. Details of the first U.S. application of bulk SAGE, including an extraction and delivery system supplying several production reactors, are discussed.

Growth Mechanism II

Wednesday AM Room: St. Tropez/Monte Carlo/Riviera
March 14, 2001 Location: Hilton San Diego Resort

Session Chair: Jerry Olson

8:20 AM
In-Situ Control of InP-Based Hetero-Interfaces with UHV-Characterization: *Thomas Hannappel*[1]; Lars Töben[1]; Christian Pettenkofer[1]; Sven Visbeck[1]; Frank Willig[1]; [1]Hahn-Meitner-Institut, SE4, Glienicker Strasse 100, Berlin D-14109 Germany

The knowledge of the electronic and atomic properties of the InP(100) surface is of crucial importance for the preparation of abrupt hetero-interfaces in thin film devices. In this paper InP-based interfaces were prepared with specific MOCVD-recipes and, after contamination-free sample transfer, investigated in ultra high vacuum (UHV). They were studied with photoelectron spectroscopy (PES), STM, LEED, and reflectance anisotropy spectroscopy (RAS) at 20 K. The formation of highly ordered surfaces is indicated by maximum peak heights and specific fine structure in RA spectra, and by pronounced valence band structures in PE spectra. The low temperature RA spectra were correlated with PES measurements that were recorded before and after exposure to excited H2 and with LEED and STM. This is shown here for the ordered (2x4) reconstructed In-terminated and for the ordered (2x1)-like reconstructed P-terminated interfaces.

8:40 AM
Effect of Hydrogen Adsorption on Reflectance Difference Spectroscopy of Indium Phosphide (001)-(2x1) Surface: *D. C. Law*[1]; Q. Fu[1]; C. H. Li[1]; Y. Sun[1]; S. B. Visbeck[1]; R. F. Hicks[1]; [1]University of California, Los Angeles, Chem. Eng. Dept., 5531 Boelter Hall, Los Angeles, CA 91007 USA

Reflectance difference spectroscopy (RDS) is a promising technique for real-time monitoring of compound semiconductor surfaces during organometallic vapor-phase epitaxy (OMVPE). However, it is difficult to assign the features in the optical spectra without first benchmarking them against well-characterized surface structures. We have found that hydrogen atoms bond relatively strongly to the indium phosphide (001), and should at least partially cover the surface during the growth process. The RDS spectra of InP are dramatically affected by adsorbed hydrogen. The positive and negative peaks seen in the spectra of the phosphorous-rich (2x1) reconstruction decrease proportionately with the hydrogen coverage, and at saturation, lack any defined structure. Vibrational spectroscopy and ab initio cluster calculations reveal that the H atoms break the phosphorous dimer bonds and attack the singly and doubly occupied dangling-bond orbitals. The implications of these results for real-time monitoring of the OMVPE process will be discussed at the meeting.

9:00 AM
Composition Modulation in GaInP Epilayers Enhanced by the Addition of Surfactants during OMVPE Growth: *Gerald B. Stringfellow*[1]; R. T. Lee[1]; C. M. Fetzer[1]; D. C. Chapman[1]; J. K. Shurtleff[1]; [1]University of Utah, College of Eng., 1495 E. 100 S., Rm. 214, Kennecott Bldg., Salt Lake City, UT 84112 USA

The use of surfactants in semiconductors during OMVPE is a powerful and exciting tool for controlling the epilayer properties. The addition of a small Sb or Bi concentration leads to the elimination of CuPt-B ordering. Additional changes occur at higher Sb concentrations. The layers spontaneously form a structure with a lateral compositional modulation (CM) in the [110] direction. Periodic surface undulations are clearly seen for the layers with CM. The low temperature PL peak energy is observed to decrease with increasing CM. The PL emission is strongly anisotropic, with a high intensity in the [1-10] direction which is the reverse of the polarization observed for CuPt ordered GaInP layers. To determine the importance of kinetics in forming the CM structure, the effect of growth rate was studied. The amplitude of the CM in layers grown with both surfactants is significantly increased for decreased growth rates. The process controlling the amplitude appears to be kinetically-limited. It is likely that adding the surfactant Sb or Bi increases the adatom surface diffusion coefficients which acts to enhance the extent of CM, especially for low grown rates.

9:20 AM
Reflectance Difference Spectroscopy of Mixed Surface Phases of Gallium Arsenide and Indium Phosphide (001): *Sven B. Visbeck*[1]; Qiang Fu[1]; Mike J. Begarney[1]; Daniel C. Law[1]; Connie H. Li[1]; Robert F. Hicks[1]; [1]University of California, Los Angeles, Chem. Eng. Dept., 5531 Boelter Hall, 405 Hilgard Ave., Los Angeles, CA 90095 USA

During MOVPE growth, the surfaces of gallium arsenide and indium phosphide exhibit mixed structures, in which the distribution among surface phases depends on the temperature and pressure of the group V precursor. In this work, we report on reflectance difference spectra of mixed phases of GaAs and InP (001), which have been benchmarked against scanning tunneling micrographs. The RDS line shape for InP is a linear combination of the spectra of the two principal surface reconstructions, the (2x1) and (2x4). By contrast, the RDS line shape for GaAs is not a simple function of the two main reconstructions, the c(4x4) and (2x4). The STM data show that a complex roughening process occurs as the arsenic coverage is decreased from 1.75 monolayers (ML) for the c(4x4) to 0.75 ML for the (2x4). This is due to gallium out-diffusion onto the surface and nucleation of small, metastable (2xn) domains (n = 2, 3 or 4) on top of the c(4x4) phase.

9:40 AM
Enhanced RDS Intensities from Thin Layers of GaAs on Vicinal (100)Ge: *J. M. Olson*[1]; W. E. McMahon[1]; [1]National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, CO 80401 USA

Despite the small lattice mismatch, the nucleation of GaAs on Ge can be strongly three-dimensional (3D). In this study we use reflectance difference spectroscopy (RDS) to study the initial stages of GaAs/Ge heteronucleation. For conditions that promote specular nucleation, i.e. low growth temperatures and low V/III ratios, the RD spectrum is essentially that of 2x4-like GaAs with positive peak intensities, at 2.6eV and 4.4eV, of less than 0.005. Increasing the V/III ratio during nucleation from 5 to 30 promotes the growth of larger 3D islands with a concomitant increase in the RD intensities of the 2.6eV and 4.4eV peaks by more than an order of magnitude. With slower growth rates and higher growth temperatures, peak intensities as large as 0.13 have been observed. Possible causes of this phenomenon are presented and discussed.

10:00 AM Break

Novel Materials

Wednesday AM Room: St. Tropez/Monte Carlo/Riviera
March 14, 2001 Location: Hilton San Diego Resort

Session Chair: Chris Wang

10:40 AM
Alternative Boron Precursors for BGaAs Epitaxy: *John F. Geisz*[1]; D. J. Friedman[1]; Sarah R. Kurtz[1]; [1]National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, CO 80401 USA

The MOVPE growth of zinc-blende $B_xGa_{1-x}As$ and $B_xGa_{1-x-y}In_yAs$ alloys with boron concentrations (x) up to 3%-5% has recently been demonstrated using diborane as a boron precursor. Growth of these alloys using diborane is complicated by many factors, such as parasitic gas-phase reactions, highly temperature-dependent boron incorporation, and limited boron incorporation before the onset of structural breakdown. These factors suggest that diborane may not be the best precursor for the growth of these alloys. We will compare the use of alternative boron precursors; trimethylboron (TMB), triethylboron (TEB), and boron trifluoride (BF_3), with diborane for the MOVPE growth of these boron containing III-V alloys.

11:00 AM
Growth and Characterization of MOVPE Grown (In,Mn) as Diluted Magnetic Semiconductor: *A. J. Blattner*[1]; B. W. Wessels[1]; [1]Northwestern University, Mats. Rsch. Ctr., 2225 North Campus Dr., Evanston, IL 60208-3108 USA

The metalorganic vapor phase epitaxy of (In,Mn)As diluted magnetic semiconductor was investigated. Trimethylindium, cyclopentadienyl-manganese and arsine were used as reactants. Single phase $In_{1-x}Mn_xAs$ films with x<0.1 were grown at a substrate temperature of 475 °C. X-ray diffraction indicated that the films were epitaxial. For x greater than 0.1, MnAs formed as a second phase. The MnAs was also nominally epitaxial. Single phase $In_{1-x}Mn_xAs$ films were p-type with carrier concentrations up to $1.4x10^{19}$ cm^{-3}. To determine their optical properties as well as the presence of impurities in the thin films, Fourier transform infrared spectroscopy was used. FTIR indicated the presence of absorption peaks at 2917 cm^{-1} and 2848 cm^{-1}. These absorption peaks are attributed to the symmetric and asymmetric vibrational stretching modes of C-H in CH_n (n=1-3) defect complexes. The C-H complexes are unintentionally incorporated during the (In,Mn)As film growth.

11:20 AM
Epitaxial Lateral Overgrowth of CdTe on GaAs Substrates using MOVPE: *Ishwara Bhat*[1]; Ruichao Zhang[1]; [1]Rensselaer Polytechnic Institute, ECSE Dept., JEC 6003, Troy, NY 12180 USA

Epitaxial lateral overgrowth (ELO) is a new technique to grow low-defect-density thin films on lattice-mismatched substrates. This technique has been successfully applied to grow high quality GaN on sapphire and SiC substrates. We have applied this method to grow low defect density CdTe on GaAs substrates using metalorganic vapor phase epitaxy. A Si3Nx mask layer of about 1000A thick was deposited on GaAs substrates and patterned using standard photolithography. The MOVPE growth was carried out using dimethylcadmium and diethyltellurium using vertical low-pressure reactor. Perfect selectivity was obtained when the temperature was >500C and pressures <30 Torr. ELO CdTe with vertical side-walls and flat-top surface could be obtained by orientating the window stripes along one of the [110] directions. For stripes along [001] orientations, the ELO CdTe had faceted structures (either triangular or inverted triangular). AFM studies indicate that selectively grown CdTe had reduced defect density and better surface morphology compared to layers grown on unpatterned regions. However, there was no discernible difference between the materials in the window region and the ELO region, indicating that the growth mechanism appears to be different compared to the mechanisms described for GaN. Complete characterization studies along with the growth mechanism will be presented at the talk.

Devices

Wednesday PM Room: St. Tropez/Monte Carlo/Riviera
March 14, 2001 Location: Hilton San Diego Resort

Session Chair: Mike Tischler

1:30 PM
Influence of Oxygen in AlGaAs-Based Laser Structures with Al-Free Active Region on Device Properties: *A. Knauer*[1]; G. Beister[1]; F. Bugge[1]; G. Erbert[1]; H. Wenzel[1]; J. Sebastian[1]; B. Sumpf[1]; M. Weyers[1]; G. Traenkle[1]; [1]Ferdinand-Braun-Institut, Mats. Tech. Div., Albert-Einstein-Str. 11, Berlin D-12489 Germany

It has been reported that oxygen incorporation in AlGaAs-based laser structures with Al-containing active region degrades the laser performance. Thus trimethyl aluminum (TMAl) sources with especially low oxygen concentration were developed for the deposition of AlGaAs by MOVPE. Additionally, Al-free active regions have been introduced for high-power laser applications. Here AlGaAs-based laser structures with GaAsP active region for emission near 730nm and 800nm were deposited from TMAl sources with different levels of oxygen contamination. Broad area laser devices were fabricated from these structures and their laser data determined. The data show, that low oxygen levels in the AlGaAs waveguide structure are especially required for shorter emission wavelengths even for laser structures with Al-free active region. For 730nm emission 7W output power and a degradation rate of 1·10-5h-1 at 2W cw (100µm stripe width x 4mm, 25C) are achieved from such structures using the TMAl source leading to the lowest O-uptake.

1:50 PM
PIN Photodetector Epitaxy Process Development in a Planetary Reactor: *Jedon Kim*[1]; D. C. Sutryn[1]; E. J. Michel[1]; F. Reinhardt[1]; [1]Lucent Technologies, Microelectronics, 2525 N. 12th St., Reading, PA 19612 USA

Successful epitaxy process development of InGaAs based PIN photodetectors on InP substrates using a planetary production metal organic chemical vapor deposition (MOCVD) reactor is reported. The PIN structure consisted of 0.5µm InP (or Q)/3.5µm (or 5.2µm) InGaAs/1.5µm InP grown on 2 inch InP substrates. InP wafer surface treatment and InP(or Q)/InGaAs interface control are found to be critical for the electrical properties of the device. Epi-ready substrates from 5 different vendors have been used and appropriate surface treatment is discussed based on the characterization results and device yield. Optimization process of the InP(or Q)/InGaAs interface is also discussed. Structural (X-ray diffraction and Transmission Electron Microscope) and electrical (Hg probe C-V) characterization techniques have been used for this optimization. Photoluminescence intensity measurement is found to be a reliable characterization technique for the prediction of the device performance and yield.

2:10 PM
Growth of InP as Current Blocking Structures for 1.55 Micron Laser: *Joseph Brian Seiler*[1]; D. C. Sutryn[1]; E. J. Michel[1]; F. Reinhardt[1]; K. Grim-Bogdan[1]; K. Hinkle[1]; V. Panayotov[1]; [1]Lucent Technologies, Microelectronics, 9999 Hamilton Blvd., Breinigsville, PA 18031 USA

Mono mode Distributed Feedback diode lasers for 1.55 micron application require focus of electrical current in areas as narrow as one micron or less. This can be achieved by selective area etching and re growth of the non-laser areas with either resisting material or reverse biased p-n junctions. We studied the epitaxial growth of a blocking structure of a capped mesa buried hetero structure (CMBH)- laser in a planetary production MOCVD reactor. The mesa definition was achieved by wet chemical etching. The mesa structure before growth consists of a silicone dioxide mask protecting the active region, while the field area is exposed to the epitaxial growth. The self-organization of non-planar surfaces with microscopic dimensions will be discussed with respect to growth parameters and device performance. High Resolution cross-sectional Scanning Electron Microscopy (SEM) and confocal microscopy reveals the development of crystallographic facets and their dopant incorporation.

2:30 PM

Growth of InGaAsP Structures over Sub-Micron Gratings in a Production Scale MOCVD Reactor: *Gayathri K. Rao*[1]; G. M. Ford[1]; C. W. Ebert[1]; T. Pinnington[1]; F. Reinhardt[1]; [1]Lucent Technologies, Microelectronics, 9999 Hamilton Blvd., Breinigsville, PA 18031 USA

Design of Distributed Feedback Laser, Modulators and selective optical components for 1.55 micron application requires epitaxial growth on non-planar sub micron gratings as well as on patterned surfaces. We studied the growth morphology and the optical properties of MQW structures, grown on top of gratings as a function of external growth parameters in a planetary commercial production reactor. High Resolution Scanning electron Microscopy (SEM), standard X-Ray and micro X-Ray, locally resolved photoluminescence and Atomic Force Microscopy (AFM) were employed to asses growth quality, MQW quality, and growth front evolution of quaternary fill-in layer on sub micron gratings. Growth enhancement of selective area growth as a function of external parameter was studied and optimized. Wafer to wafer and run to run wavelength reproducibility will be presented as well as device data in manufacturing mode.

2:50 PM

Design of Vertical Tapers Using Selective-Area Epitaxy with Quantitative Modeling: *Jonathan E. Greenspan*[1]; Ian Betty[1]; Richard Glew[1]; Robert Foster[1]; [1]Nortel Networks, PO Box 3511, Ottawa, Ontario K1Y 4H7 Canada

Next generation photonic systems require components integrating two or more devices. For example, better coupling into a fiber can be achieved by integrating a laser with an optical spot-size converter (SSC). One approach to implementing a SSC is with a vertical taper. We report on a method for fabricating vertical tapers integrated with an active device in an MOCVD reactor. Quantitative modeling of the selective-area growth process is used to determine the mask dimensions required to deposit a waveguide core with a thickness profile previously optimized by beam propagation calculations. Modeling is also used to predict the composition and strain shifts caused by growth in the presence of the dielectric masks, and to minimize the peak strain shift. Measurements using spatially resolved photoluminescence, energy dispersive x-ray analysis, and surface profiling are reported to demonstrate the validity and usefulness of the model.

3:10 PM Break

Safety

Wednesday PM — Room: St. Tropez/Monte Carlo/Riviera
March 14, 2001 — Location: Hilton San Diego Resort

Session Chair: Raj Bhat

3:30 PM

Compound Semiconductor Gas Product Stewardship: *Eugene Y. Ngai*[1]; [1]Solkatronics, Morrisville, PA USA

Many of the Electronic Specialty Gases (ESG) used in growing compound semiconductor devices are highly toxic, corrosive and/or pyrophoric. To reduce the risk in the Filling, Use and Transportation of these, Solkatronic Chemicals has an active Responsible Care program, which examines the Gases throughout their life cycle. Over the last ten years, Solkatronic has examined a variety of issues related to package integrity, Emergency Response, Safety for the ESG products. The presentation will summarize some of the recent safety studies: Cylinder Valve Impact Testing Cylinder Leak TestingPhysical Testing (Hydrogen Selenide Flammability, Phosphine Pyrophoricity)

3:45 PM

Safe Handling of Liquid Organometallics via an Automated Bulk Delivery System: *Ravi Kanjolia*[1]; Stan Pryll[1]; Richard Pearce[1]; Graham Williams[2]; [1]Epichem, Inc., 26 Ward Hill Ave., Haverhill, MA 01835 USA; [2]Epichem, Ltd., Power Rd., Bromborough, Wirral CH623QF UK

The inherent hazard associated with organometallic precursors in MOCVD is their pyrophoricity and the toxicity of the resultant by-products. For example, trimethylgallium ignites in air to form gallium oxide, which is a known irritant on inhalation, and a moderately toxic oxide. As MOCVD technology moved into production, the handling of OM bubblers has increased considerably at fabrication facilities. The large-scale consumption of OM's has resulted in increased handling in a number of organizational units including shipping & receiving, storage, and operations. The automated, bulk OM delivery system- EpiFill is a safe and cost effective system that reduces operator intervention for bubbler change-out, and minimizes handling by shipping, receiving, and stores personnel. This system was developed to reduce reactor downtime, reduce qualification cycles, and increase safety at MOCVD growth facilities.

4:00 PM

Advancements in Safe Delivery of Hydride Gases for III-V Manufacturing: *Jim Dietz*[1]; Ray Dubois[1]; Jim Mayer[1]; [1]ATMI, Inc., 7 Commerce Dr., Danbury, CT 06810 USA

The manufacture of III-V compounds via chemical vapor deposition requires the use of highly toxic arsine and phosphine gases. On the facilities side, manufacturers have implemented automated gas delivery systems, multi-point gas monitoring, and one or more emergency gas scrubbers to manage the risk of using these toxic liquified gases. On the process side, film quality is highly dependent on hydride gas quality both over the life of a cylinder and from cylinder to cylinder. As compound semiconductor wafer starts increase to meet the growing demand for compound semiconductors, the demand from III-V fabricators for arsine and phosphine will grow accordingly. With this increase in demand for both arsine and phosphine, an increased risk associated with the higher use of these toxic, flammable dopants is ever present. The paper will discuss the requirements and possibilities for installing mini-bulk sources of arsine and phosphine using a sub-atmospheric pressure delivery system to reduce the potential for catastrophic releases of arsine and phosphine. The paper will present process data on deposited III-V films to demonstrate the viability of using sub-atmospheric pressure sources. Last, the paper will describe implementation of mini-bulk arsine and phosphine in new and existing fabricators to decrease the risk of storing large volumes of hydrides.

4:15 PM

Safety of Metalorganics during Transportation and Storage: *Jim Dixon*[1]; [1]EMF, Ltd., Cambridge, UK

The amounts of Metalorganics used has increased dramatically over the past few years; in terms of the number of users and the quantities shipped. In addition the quantities stored on site has also increased to keep pace with increasing production requirements. In order for the work to be carried out safely, we studied methods of extinguishing metalorganic fires. Investigations were carried out to examine the efficacy of the packing requirements as defined by international regulations in terms of crash and fire resistance. Also examined were the effects of escaping Metalorganics into the shipping containers.

4:30 PM

Appropriate PPE for Pyrophoric Materials: New Evaluations: *Curtis Post*[1]; Greg Smith[1]; Eric Majoor[1]; [1]Akzo Nobel, Deer Park, TX USA

Most of the organometallics used in MOCVD processes possess particular inherent hazards. They are pyrophoric and react violently with water. These chemicals can, however, be handled safely using good safety practices and proper Personal Protective Equipment (PPE). Recent experience at Akzo Nobel implied a need for improved PPE for handling pyrophoric organometallics and suggested that PPE evaluations based on small scale tests conducted in the past were not fully predictive of field performance. Akzo has now conducted small-scale lab PPE tests, larger scale lab PPE tests, and field-scale tests of complete PPE ensembles to establish stringent and reliable standards for pyrophoric organometallics handling PPE. A variety of materials of construction for gloves, outer and inner garments, face shields and hoods were tested under controlled conditions to determine the optimum PPE required for each task to be performed. Based on the findings of these tests, Akzo Nobel recommends specific PPE for personnel performing potentially hazardous tasks. These include: removing caps from product cylinder inlets and outlets of cylinders containing High Purity Metalorganics; breaking connections between process equipment and product cylinders; and opening lines or equipment formerly containing pyrophoric organometallics that are not definitely known to be free of pyrophoric materials. The PPE recommended for each situation is predicated upon a philosophy of providing complete protection for all parts of a worker when product spills or leaks are possible. Experience has shown that it is important to not leave any part of the worker exposed and that even small spills can cause serious harm to unprotected personnel. Akzo Nobel also offers a Safety Self-Audit Checklist or, upon request, will come to your facility and perform a Safety Audit at no charge.

4:45 PM
Safe Handling of Organometallics: *Robert Stennick*[1]; [1]Hass Company, North Andover, MA 01845 USA

Metalorganic compounds used in vapor phase epitaxy are generally regarded as hazardous materials and exhibit varying degrees of spontaneous combustibility and toxicity. For over 30 years, these products have been safely used for the growth of compound semiconductor films. This presentation will review the hazardous properties of metalorganics, safe handling and actions useful in the event of an accidental release. Finally, proactive measures to ensure the continued safe application of these products will be discussed.

5:00 PM User Comments/Discussion

Nitrides I

Thursday AM — Room: St. Tropez/Monte Carlo/Riviera
March 15, 2001 — Location: Hilton San Diego Resort

Session Chair: Russ Dupuis

8:20 AM
Mechanisms of Dislocation Reduction in GaN using an Intermediate Temperature Interlayer: *E. D. Bourret-Courchesne*[1]; M. Benamara[1]; Z. Liliental-Weber[1]; J. Washburn[1]; [1]E.O. Lawrence Berkeley Laboratory, 1 Cyclotron Rd., M.S. 2-200, Berkeley, CA 94720 USA

A reduction of the dislocation density in GaN by three to four orders of magnitude was obtained by insertion of a single thin interlayer grown at an intermediate temperature (IT-IL) after the initial growth at high temperature. A description of the growth process is presented with characterization results aimed at understanding the mechanisms of reduction in dislocation density. A large percentage of the threading dislocations present in the first GaN epilayer are found to bend in the interlayer and do not propagate in the top layer grown at higher temperature in a lateral growth mode. TEM studies show that the mechanisms of dislocation reduction are similar to those described for the epitaxial lateral overgrowth process, however a notable difference is the absence of coalescence boundaries. The role of stress on the microstructure of the GaN obtained by the IT-IL process will be described.

8:40 AM
Progress in Planar Growth of GaN on Si(111): Hugues Marchand[2]; *Brendan Moran*[1]; Lijie Zhao[1]; Naiqian Zhang[2]; Rob Coffie[2]; James S. Speck[1]; Umesh K. Mishra[2]; Steven P. DenBaars[1]; [1]University of California, Dept. of Matls., Santa Barbara, CA 93117 USA; [2]University of California, Dept. of Elect. & Comp. Eng., Santa Barbara, CA 93117 USA

Two schemes of nucleation and growth of gallium nitride on Si(111) substrates are investigated and the structural and electrical properties of the resulting films are reported. Gallium nitride films grown using a 10-500 nm-thick AlN buffer layer deposited at high temperature (~1050°C) are found to be under 260-530 MPa of tensile stress and exhibit cracking, the origin of which is discussed. The threading dislocation density in these films increases with increasing AlN thickness, covering a range of 1.1E 9 cm-2 to >5.8E 9 cm-2. Films grown using a thick, AlN-to-GaN graded buffer layer are found to be under compressive stress and are completely crack-free. Heterojunction field effect transistors (HFETs) fabricated on such films result in well-defined saturation and pinch-off behavior with a saturated current of ~525 mA/mm and a transconductance of ~100 mS/mm in DC operation.

9:00 AM
The Influence of Process Conditions on the Growth of Group-III Nitrides in Production Type MOCVD Planetary Reactors®: *B. Schineller*[1]; O. Schoen[1]; H. Protzmann[1]; M. Luenenbuerger[1]; A. Alam[1]; *M. Heuken*[1]; M. Juergensen[1]; [1]Aixtron AG, Kackertstr 15 - 17, Aachen D-52072 Germany

We investigated the growth of InGaN/GaN MQW in the single wafer AIX 200 RF system and the production type AIX 2000 G3 HT in the 6 x 2 inch and 5 x 3 inch configuration. The formation of luminescent quantum dots was found to be enhanced with decreasing growth temperature and increasing In content in the gas phase. Higher reactor total pressures were found to lead to higher In incorporation without enhancing the amount of phase separation. In full loaded runs we were able to tune the wavelengths through the visible spectrum with wafer to wafer standard deviations of 0.9% at 441.5 nm, 1.4% at 470.7 nm, 1.3% at 499.3 nm, and 0.3% at 579.8 nm. We will show additional data on electrical, optical and structural properties of various layer structures which are commonly used as building blocks for device fabrication. A special focus will be on the reproducibility and yield determining factors.

9:20 AM
InGaN/GaN Quantum Well Growth on GaN Stripes Formed by Lateral Epitaxial Overgrowth: *Xingang Zhang*[1]; P. D. Dapkus[1]; Dawei Ren[1]; D. H. Rich[2]; [1]University of Southern California, Compound Semicond. Lab., 3651 Watt Way, VHE 313, Los Angeles, CA 90089-0243 USA; [2]University of Southern California, Dept. of Mats. Sci., 3650 Watt Way, VHE 607, Los Angeles, CA 90089-0241 USA

InGaN/GaN QWs have been grown on top of LEO GaN mesa stripes which have atomically smooth inclined sidewalls and 2 μm wide flat tops. These mesa stripes are uniquely formed by coalescence of two adjacent LEO GaN stripes each with the triangular cross section. Threading dislocations (TD) in the center of the coalesced region are reduced by the mask blocking process and by TD bending since the two coalescence GaN stripes have the inclined {1101} sidewalls. Our preliminary MOCVD growth and cathodoluminescence (CL) studies show strong In spatial migration. Two distinct emission peaks at 390 nm and 430 nm are observed in the spectra that originate, respectively, from the sidewalls and mesa top. CL images revealed that both the top QW emission at 430nm and the sidewall emission at 390nm are uniform and strong. This is in sharp contrast to QW growth on planar GaN buffer that usually shows strong In phase segregation and carrier localization.

9:40 AM
OMVPE Growth of p-Type GaN using Solution Magnesocene: *Yundong Qi*[2]; Charles Musante[2]; Kei May Lau[1]; Raj Odedra[3]; Ravi Kanjolia[4]; Lesley Smith[3]; [1]Hong Kong University of Science & Technology, EEE Dept., Clear Water Bay, Kowloon, Hong Kong; [2]University of Massachusetts/Amherst, ECE Dept., Amherst, MA 01003 USA; [3]Epichem, Ltd., UK; [4]EpiChem, 26 Ward Hill Ave., Haverhill, MA 01835 USA

Bis(cyclopentadienyl)magnesium, (Cp2Mg) is a common source for p-type doping in GaN and AlInGaP materials. However, it is a white crystalline solid with very low vapor pressure. This makes its usage in the MOCVD application very difficult due to the typical problems associated with the transport of the solid. Furthermore, the problem is compounded by the very low vapor pressure resulting in significant memory effect. Some of these problems can be overcome by the new source- Solution magnesocene. In this source, Cp2Mg is dissolved in a solvent that is essentially non volatile. The advantage of this approach is a consistent delivery of the magnesium source with essentially identical vapor pressure of Cp2Mg. We investigated the growth of Mg-doped GaN by OMVPE using solution Cp2Mg. At 100 torr growth pressure and 1030°C growth temperature, comparison is made using solution Cp2Mg and conventional solid Cp2Mg. All the Mg-doped GaN are activated at 750°C in nitrogen ambient environment for 30 minutes. Low resistivity p-type GaN with Hall hole concentration in the mid-10E17 cm-3 range has been achieved using both solid and liquid sources. We believe higher levels are achievable with further optimization.

10:00 AM Break

Nitrides II

Thursday AM — Room: St. Tropez/Monte Carlo/Riviera
March 15, 2001 — Location: Hilton San Diego Resort

Session Chair: Andy Allerman

10:40 AM
Comparison of AlGaN/GaN Heterojunction Field-Effect Transistors Grown on Sapphire and SiC Substrates by Metalorganic Chemical Vapor Deposition: Bryan S. Shelton[1]; Shyh-Chiang Shen[2]; Damien J. H. Lambert[1]; Tinggang Zhu[1]; Michael M. Wong[1]; Uttiya Chowdhury[1]; Ho Ki Kwon[1]; Ki-Soo Kim[1]; Jonathan C. Denyszyn[1]; Milton Feng[2]; *Russell D. Dupuis*[1]; [1]The University of Texas at Austin, Microelect. Rsch. Ctr., PRC/MER-R9900, Austin, TX 78712-1100 USA; [2]University of Illinois at Urbana-Champaign, Ctr. for Compound Semiconductor Microelectr., 208 North Wright St., Urbana, IL 61801 USA

The influence of the substrate on the properties of AlGaN/GaN heterojunction field-effect transistors (HFETs) grown by low-pressure metalorganic chemical vapor deposition is described. The AlGaN/GaN HFETs are grown by low-pressure MOCVD on (0001) sapphire and n-SiC substrates. The epitaxial structures are grown at ~200 and (~50 Torr for AlGaN layer) in a hydrogen ambient using trimethylgallium, trimethylaluminum, and ammonia. The HFET structures are completely undoped, gaining their charge from piezoelectric and spontaneous polarization effects of the AlGaN/GaN interface. The role of the substrate on the mobility and sheet charge are examined through variable-temperature Hall effect and C-V measurements. Optimizations of the growth conditions in the transition from the GaN layer to the AlGaN layer are examined from the standpoint of mobility and through the use of AFM RMS roughness. Both 2µm and 0.25µm HFET devices have been fabricated with the highest transconductance values of 190 mS/mm and 300-400 mS/mm, respectively.

11:00 AM
Optimization of AlGaN Back-Illuminated Solar-Blind MSMs Grown by Metalorganic Chemical Vapor Deposition: Damien J. H. Lambert[1]; Bo Yang[1]; Ting Li[1]; Charles J. Collins[1]; Michael M. Wong[1]; Uttiya Chowdhury[1]; Bryan S. Shelton[1]; Ariane L. Beck[1]; Ho Ki Kwon[1]; Tinggang Zhu[1]; Jonathan C. Denyszyn[1]; Joe C. Campbell[1]; *Russell D. Dupuis*[1]; [1]The University of Texas at Austin, Microelect. Rsch. Ctr., PRC/MER-R9900, Austin, TX 78712-1100 USA

We report the optimization of back-illuminated solar-blind metal-semiconductor-metal (MSM) photodetectors, grown by MOCVD. We have varied the growth conditions (e.g., growth temperature, growth rate, growth pressure) and have studied the correlation of the symmetric and asymmetric X-ray diffraction line widths, surface morphology, and cathodoluminescence upon the MSM device performances. $Al_{0.44}Ga_{0.56}N$ layers with various thicknesses have been used as the active region in these structures. All the samples employed the same $Al_{0.58}Ga_{0.42}N$ window layer and AlN buffer layer. We find that the performance of the MSMs is highly dependant on the crystal quality of the active region. Specifically, the use of thin strained compared to thicker relaxed $Al_{0.44}Ga_{0.56}N$ active regions greatly reduces the leakage current of the MSMs. The relaxation presumably creates defects that are responsible for the large leakage currents. By optimizing the grow th conditions, we have fabricated solar-blind MSM photodetectors having a 48% external quantum efficiency for wavelengths λ ~262 nm.

11:20 AM
UVLEDs with AlInGaN/InGaN and AlGaN/InGaN Active Regions Grown by OMVPE: *Gregory M. Peake*[1]; A. J. Fischer[1]; J. Han[1]; J. J. Figiel[1]; C. C. Mitchell[1]; R. M. Biefeld[1]; [1]Sandia National Laboratories, PO Box 5800 MS 0601, Albuquerque, NM 87185-0601 USA

III-N Ultra Violet Light Emitting Diodes (UVLEDs) are important for lighting, curing and sensing applications. We will present recent results for UVLEDs with InGaN quantum wells and AlInGaN or AlGaN barriers grown by OMVPE. Improved light extraction techniques have doubled the output of our LEDs by using a bottom reflector of Al deposited by e-beam evaporation. We have also used a modified contact geometry to reduce current crowding. Physical and optical measurements of our most recent diodes will be presented. We will also present strategies for reaching wavelengths < 350 nm.

11:40 AM
MOCVD Growth and Characterization of AlGaN/GaN/GaInN Vertical Cavity Surface Emitting Laser: *Jung Han*[1]; Karen E. Waldrip[1]; Jeffrey J. Figiel[1]; Hailong Zhou[2]; Eleni Makarona[2]; Arto V. Nurmikko[2]; [1]Sandia National Laboratories, Chem. Proc. Sci., MS-0601, PO Box 5800, Albuquerque, NM 87185 USA; [2]Brown University, Div. of Eng., Providence, RI 02912 USA

One of the most challenging issues in growing nitride-based DBR mirrors is sample cracking due to the tensile mismatch between AlGaN and GaN. In this talk we will demonstrate stress management using AlN interlayers. The modulation and evolution of stress during growth of AlGaN and GaN layers was clearly resolved by an in-situ stress monitor. Nomarski microscopy from a 60-pair DBR structure (~5 um thick) indicated an essentially crack-free surface. Reflectivities up to and beyond 99% have been measured from GaN/AlGaN multilayer DBR stacks with a peak wavelength varying from 370 to 420 nm. The in-situ DBRs have been incorporated into vertical cavity structures which include GaN:In active QW light emitter region and high reflectivity SiO2/HfO2 dielectric DBRs. Optically pumped near ultraviolet vertical cavity laser operation has been obtained under quasi-continuous wave conditions at room temperature near 383 nm from shallow InGaN/GaN multiple quantum wells. Sandia is a multiprogram laboratory, operated by Sandia Corporation, a Lockheed Martin company, for the United States Department of Energy, under contract DE-AC04-94AL85000.

12:00 PM Closing Remarks

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