SYMPOSIUM O

Substrate Engineering–Paving the Way to Epitaxy

November 29 – December 2, 1999

Chairs

David H. Matthiesen
Dept of MS&E
Case Western Reserve Univ
420 White Bldg
Cleveland, OH 44106
216-368-1366

Nate Newman
Electrical & Computer Engr Dept
Northwestern Univ
M250
Evanston, IL 60208-3118
847-491-8137

David P. Norton
Solid State Div
Oak Ridge National Lab
MS-6056 Bldg 2000
Oak Ridge, TN 37831-6056
423-574-5965

Darrell G. Schlom
Matls Science Dept
Pennsylvania State Univ
103 Steidle Bldg
University Park, PA 16802-5005
814-863-8579

Symposium Support
American Association for Crystal Growth
American Dicing, Inc.
ATMI Ventures
†Cree Research, Inc.
†Princeton Scientific Corp.
TLI Enterprises, Inc.
†1999 Fall Exhibitor

Proceedings published as Volume 587 of the Materials Research Society Symposium Proceedings Series.

* Invited paper

SESSION O1/W2: JOINT SESSION:
LATERAL EPITAXIAL OVERGROWTH
Chair: Colin E.C. Wood
Monday Afternoon, November 29, 1999
Room 302 (H)

1:30 PM *O1.1/W2.1

PENDEO-EPITAXIAL GROWTH OF GaN AND RELATED MATERIALS ON 6H-SiC(0001) AND Si(111) SUBSTRATES AND THEIR CHARACTERIZATION. Robert F. Davis, T. Gehrke, Kevin J. Linthicum, E.P. Carlson, P. Rajagopal, E.A. Preble, D L. Nida, C.A. Zorman* and M. Mehregany*, Department of Materials Science and Engineering, North Carolina State University, Raleigh, NC; *Department of Electrical, Systems and Computer Engineering and Science, Case Western Reserve University, Cleveland, OH.

Pendeo (from the Latin: to hang or be suspended from)-epitaxy (PE) is a method of growing large area thin films with a low-defect density. It incorporates mechanisms of growth exploited by conventional lateral growth processes by using masks to prevent vertical propagation of threading defects, and extends the phenomenon to employ the substrate itself as a pseudo-mask. The growth does not initiate through open windows, rather it begins on sidewalls of forms etched into a seed layer and continues until coalescence over and between the seed structures occurs, resulting in a single complete layer. The PE growth of GaN and AlGaN alloys via MOVPE and the use of silicon nitride and nickel etch masks has been the focus of this investigation. The three main stages of PE growth, namely (i) initiation of selective lateral homoepitaxy from the seed sidewalls of the nitrides, (ii) vertical growth and (iii) lateral growth over the silicon nitride masked seed structure to form both discrete microstructures and coalesced single crystal layers will be described for these materials. These processing procedures and the aforementioned stages be accompanied in this presentation by supporting structural, microstructural, optical and electrical evidence.

2:00 PM O1.2/W2.2

HIGH-QUALITY COALESCENCE OF LATERALLY OVERGROWN GaN STRIPES WITH LOW WING TILT. P.T. Fini, L. Zhao, B. Moran, M. Hansen, H. Marchand, J.P. Ibbetson, S.P. DenBaars, U.K. Mishra, J.S. Speck, Dept. of Materials Science and Dept. of Electrial and Computer Engineering, University of California, Santa Barbara, CA.

Despite recent demonstrations of improved device performance on laterally epitaxially overgrown (LEO) GaN compared to conventional GaN films on sapphire, difficulties remain in controlling the structural quality of the overgrown material during coalescence between neighboring features ((*e.g.* stripes). In the LEO of GaN from $<1\bar{1}00>_{GaN}$ or $<11\bar{2}0>_{GaN}$-oriented stripes, it has been observed that the 'wings' (laterally overgrown GaN) exhibit tilts away from the 'window' (seed) regions, in an azimuth perpendicular to the stripe direction. These tilts, often greater than 1°, may be readily observed as a splitting of the ω rocking curve about the central (window GaN) 0002 peak in x-ray diffraction. In this method, the stripes are aligned such that the scattering plane (defined by incident and diffracted wave vectors) is perpendicular to the $<1\bar{1}00>$ stripe direction. Wing tilt has been correlated with the ratio of wing width (w) to height (h), which is directly dependent on growth conditions (*e.g.* V/III ratio, temperature) and 'fill factor' (the ratio of open width to pattern period). Since wing tilt increases as w/h increases, low wing tilt may be achieved through careful control of the stripe cross-sectional aspect ratio. We have characterized low-tilt LEO GaN stripes grown on large-area (2 inch) $SiO_2/GaN/Al_2O_3$ wafers by low-pressure metalorganic chemical vapor deposition (MOCVD) before and after coalescence. Using scanning electron microscopy (SEM), x-ray diffraction (XRD), trasnsmission electron microscopy (TEM), and atomic force microscopy (AFM), it is shown that by first obtaining wings with low tilt relative to the seed GaN, very few extended defects are formed when wings from neighboring stripes coalesce. After wings with a tilt of $\sim$0.1° are coalesced and an additional $\sim$10 μm of GaN is grown, it is found with XRD that ω peak splitting due to tilt is no longer detectable. TEM and AFM results show that few dislocations (with a linear density of $<4\times10^3$ cm^{-1}) are formed at coalescence fronts.

2:15 PM O1.3/W2.3

FABRICATION OF GaN WITH BURIED TUNGSTEN (W) STRUCTURES USING EPITAXIAL LATERAL OVERGROWTH (ELO) AND THEIR CHARACTERIZATION. Kazumasa Hiramatsu, Hideto Miyake, Atsushi Motogaito, Dept of Electrical and Electronic Engineering, Mie Univ, Mie, JAPAN; Yasutoshi Kawaguchi, Shingo Nambu, Nobuhiko Sawaki, Dept of Electronic Engineering, Nagoya Univ, Nagoya, JAPAN; Yasushi Iyechika, Takayoshi Maeda, Sumitomo Chemical Co. Ltd, Tsukuba, JAPAN.

Epitaxial lateral overgrowth (ELO) of GaN with tungsten (W) mask via MOVPE or HVPE is one of the most promising techniques for obtaining not only buried metal structures such as a SIT device but also an ELO-GaN layer with high quality crystalline quality. We will present recent successful results on ELO of GaN with stripe W mask pattern via MOVPE and HVPE. The buried W structure using ELO of GaN is performed by HVPE and a thick buried structure of the W mask with a smooth surface is achieved for the stripe mask patterns along $< 11\bar{2}0 >$ and $< 1\bar{1}00 >$. Optical and crystalline characteristics of the ELO-GaN are investigated by means of AFM, CL, TEM and x-ray rocking curve. Thus, those characterizations show evidence of highly crystalline quality with atomically flat surface, uniformly perfect excitonic emission, no c-axis tilting and no small angle grain boundaries, in comparison with a buried structure of SiO_2 mask. Furthermore, a thin GaN with buried W structure is achieved by MOVPE for stripe mask pattern $< 1\bar{1}00 >$. The W has a severe catalytic effect to attack the underlying GaN layer with a hydrogen ambient at a high temperature. To prevent decomposition of GaN layer, we employed ELO of GaN at temperatures below 1000°C under a low reactor pressure (<300 or <300 Torr)which allows us to enhance the lateral overgrowth. Consequently, the W mask was buried without damage to the underlying GaN and their crystalline and electrical properties and characterized for aiming at the SIT device.

2:30 PM O1.4/W2.4

ADVANCED PENDEO-EPITAXIAL GROWTH OF GaN THIN FILMS ON SiC(0001) AND Si(111) SUBSTRATES VIA METALORGANIC CHEMICAL VAPOR DEPOSITION AND THEIR STRUCTURAL, MICROSTRUCTURAL, OPTICAL AND ELECTRICAL CHARACTERIZATION. T. Gehrke, K.J. Linthicum, E.A. Preble, E.P. Carlson, P. Rajagopal and R.F. Davis, Department of Materials Science and Engineering, North Carolina State University, Raleigh, NC.

Growth of GaN thin films with low densities of defects on Si(111) and 6H-SiC(0001) substrates using pendeo-epitaxial (PE) techniques and the characterization of the resulting material are reported. Pendeo-epitaxy is a new form of selective epitaxial growth that is dominated by the growth from sidewalls of rectangular stripes. This process route allows the growth of uniformly low defect density material over the entire surface of the semiconductor. Similar to LEO growth, a mask is employed to prevent vertical propagation of threading dislocations from the GaN seed forms into the regrown areas. The use of a mask can cause the formation of boundaries at the interface of coalescence of two growth fronts and a crystallographic tilt in the adjacent regions that have overgrown the mask. Assemblies of GaN films grown on Si substrates usually show a high density of cracking caused by the difference in the coefficients of thermal expansion of the two materials. Advanced processing routes to achieve PE growth on the aforementioned substrates have been investigated to reduce the formation of coalescence boundaries, the tilt in the overgrown regions, and the cracking in the coalesced GaN films. Microstructural results via transmission electron microscopy and scanning electron microscopy, as well as low temperature photoluminescence and X-ray diffraction spectra, and the data from various electrical investigations have been obtained and will be integrated with the growth results in the presentation and the associated paper.

2:45 PM O1.5/W2.5

Abstract Withdrawn.

3:30 PM O1.6/W2.6

DISLOCATION MECHANISMS IN THE GaN LATERAL OVERGROWTH BY HYDRIDE VAPOR PHASE EPITAXY. T.S. Kuan, C.K. Inoki, Y. Hsu, D.L. Harris, State Univ of New York at Albany, Dept of Physics, Albany, NY; R. Zhang, S. Gu, T.F. Kuech, Univ of Wisconsin, Dept of Chemical Engineering, Madison, WI.

We have carried out a series of lateral epitaxial overgrowths (LEO) of GaN through thin oxide windows by the hydride vapor phase epitaxy (HVPE) technique under different growth conditions to determine the major factors that govern the dislocation propagation behavior during growth. Electron microscopy and stress simulations are used to investigate the dislocation structure and mechanisms responsible for the tilting of the LEO regions. The growth morphology is most sensitive to the growth temperature. High lateral growth rate at 1100°C allows coalescing of neighboring islands into a continuous and flat film, while the lower lateral growth rate at 1050°C produces triangular-shaped ridges over the growth windows. In either case, threading dislocations bend into laterally grown regions to relax the shear stress developed in the film during the growth. In regions close to the mask edge, where the shear stress is the highest, dislocations interact and multiply into arrays of edge dislocations lying parallel to the growth window. This multiplication and pileup of dislocations, most likely via the Frank-Read type operation, cause a large-angle tilting of the laterally grown regions. The angle of tilt is high($\sim$8 degrees) when the growth is at 1050°C and becomes smaller (3-5

degrees) at 1100°C. At the coalescence of growth facets, a tilt-type grain boundary is formed. During the high-temperature lateral growth, the tensile stress in the GaN seed layer and the thermal stress from the oxide mask layer both contribute to a high shear stress at the growth facets. Finite element stress simulation results indicate that the shear stress close to the oxide mask edge can reach 0.1 GPa or higher, which is sufficient to cause the observed excessive dislocation activities and tilting of LEO regions at high growth temperatures.

3:45 PM O1.7/W2.7

GaN LAYERS GROWN BY NANO EPITAXIAL LATERAL OVERGROWTH TECHNIQUE ON POROUS GaN. M. Mynbaeva, A. Titkov, A. Kryzhanovski, A. Zubrilov, V. Ratnikov, V. Davydov, N. Kuznetsov, K. Mynbaev, Ioffe Institute, St. Petersburg, RUSSIA; D. Tsvetkov, S. Stepanov, A. Cherenkov, I. Kotousova, Crystal Growth Research Center, St. Petersburg, RUSSIA; and V. Dmitriev, TDI, Inc., Gaithersburg, MD.

Defect density and stress reduction in heteroepitaxial GaN is one of the main issues in GaN technology. Recently, significant progress in defect density reduction in GaN layers has been achieved using lateral overgrowth technique. In this paper, we describe a novel technique based on nano-scale epitaxial lateral overgrowth (NELOG), for the first time. GaN layers were overgrown by hydride vapour phase epitaxy on porous GaN. Porous GaN was formed by anodization of GaN layers grown previously on SiC substrates. Pore's size was in nano-scale range. It is important that NELOG technique does not require any mask. This technique may be easily scaled for large area substrates. Thickness of overgrown layers ranged from 2 to 70 microns. It was shown that GaN layers overgrown on porous GaN have good surface morphology and high crystal quality. The surface of overgrown GaN material was uniform and flat without any traces of porous structure. X-ray, photoluminescence, and Raman measurements indicated that the stress in the layers grown on porous GaN was reduced down to 0.1 - 0.2 GPa, while the stress in the layers grown directly on 6H-SiC substrates remains at its usual level of about 1 GPa. We propose porous GaN to be used as buffer layer for stress-reduced GaN device structures and bulk material.

4:00 PM O1.8/W2.8

LOW DEFECT GaN USING MASS TRANSPORT. Shugo Nitta, Michihiko Kariya, Takayuki Kashima, Shigeo Yamaguchi, Hiroshi Amano and Isamu Akasaki, Dept of Electrical and Electronic Engineering and High-Tech Research Center, Meijo Univ, Nagoya, JAPAN.

Mass transport phenomena and bending of the threading dislocations is observed in GaN for the first time. GaN 7μm in thickness was grown at 1100°C on a sapphire (0001) substrate using low temperature deposited AlN buffer layer by MOVPE. Squared grooves along [11-20] direction were patterned by RIE. The width and depth of grooves were 3.5μm and 2.5μm, respectively. Then, the wafer was annealed at 1000°C in MOVPE reactor with nitrogen and ammonia. During annealing, no group-III alkyl source gas was supplied. After 10 min annealing, most of stripe region were buried by mass transport. TEM observation revealed that defect-free region were formed on the stripe region due to bending of threading dislocations by mass transport. This method is superior to epitaxial lateral overgrowth method because it is mask-free and there is no impurity diffusion from the mask. GaN 3μm in thickness was continuously grown after mass transport. Above stripe region, defect-free GaN were also grown. Device properties fabricated by using this mass transport method will be shown. This work was partly supported by JSPS.

4:15 PM O1.9/W2.9

FORMATION OF GROWTH DOMAINS IN EPITAXIAL LATERAL OVERGROWN GaN ON TUNGSTEN MASKS - DIRECTLY EVIDENCED BY CATHODOLUMINESCENCE MICROSCOPY AND MICRO-RAMAN SPECTROSCOPY. F. Bertram, T. Riemann, D. Rudloff, J. Christen, Inst of Exp Physics, Univ of Magdeburg, GERMANY; A. Kaschner, A. Hoffmann, TU Berlin, GERMANY; K. Hiramatsu, Mie University, Mie, JAPAN.

Employing the technique of epitaxial Lateral Overgrowth (ELO) to the group-III nitrides has been proven successful in significantly reducing the concentration of threading dislocations emanating from the underlying buffer layer. The ELO approach is based on masking parts of the defective crystalline substrate GaN *seed* layer with an amorphous mask layer so that the dislocations are prevented from propagating into the overlayer during subsequent regrowth. However, it is reported that the impurities are unintentional incorporated in the lateral overgrown GaN although the biaxial strain and defect concentration are reduced on the top of the mask. Generally a silicon mask are employed. Epitaxial lateral overgrown GaN structures using tungsten masks oriented in different crystallographic directions ($<11\bar{2}0>$ and $<1\bar{1}00>$) are comprehensively characterized by scanning cathodoluminescence (CL) microscopy and micro-Raman-spectroscopy. By means of highly spatially resolved CL and μ-Raman investigations, we are able to correlate the optical and structural properties of these ELOG structures on a microscopic scale. Different growth domains are directly imaged. Cross sectional CL microscopy directly visualize the significant differences between the coherently grown seeding regions (between the tungsten-stripes) and the overgrown areas. The overgrown GaN shows a strong blue-shift and broadening of the luminescence, while the CL from the coherent areas is dominated by the strain-shifted narrow (D^0, X)-emission. In the CL wavelength image the growth domains of the ELO region are directly identifiable. The micro-Raman measurements show a fundamental other behavior of ELO structures using tungsten mask than using silicon mask. The strain relaxation occurs exponential, however, is not such efficient as with a silicon mask. The overgrown region shows high free carrier concentration, i.e. a strong impurity incorporation.

4:30 PM O1.10/W2.10

SELECTIVE AREA GROWTH STUDIES OF COALESCENCE MECHANISMS IN GaN CVD. Michael E. Bartram, Michael E. Coltrin, Christine C. Willan and Jung Han, Sandia National Laboratories, Albuquerque, NM.

In addition to reducing defect concentrations, selective area growth techniques can provide arrays of well-defined GaN islands for studying coalescence mechanisms under carefully controlled conditions. We have used this approach to observe that the intersection of slow growing [11-0n] facets, occurring at the point of convergence between adjacent islands, can open an avenue for growth in the more favorable $<112-n>$ crystallographic direction. In this mechanism, growth takes place only a layer at a time in a step-flow fashion on these facets. However, rapid accumulation of these layers can drive growth in the opposing $<11-0n>$ lateral direction as well as the $<0001>$ vertical direction at an unexpectedly high rate. These observations explain in molecular terms how rapid surface smoothing of GaN occurs and why this is often observed in the presence of the otherwise slow growing [11-0n] facets in hexagonal pits. Specifically, since nucleation of each layer begins at facet intersections, low surface area facets grow more quickly until adjacent facets have equal areas. This enhancement effect results in pits of high symmetry (hexagonal) during the latter stages of coalescence. (Sandia is operated by Sandia Corporation, a Lockheed Martin Company, for the USDOE under DE-AC04-94AL85000.)

4:45 PM O1.11/W2.11

DISLOCATION ARRANGEMENTS IN THICK LEO GaN. K.A. Dunn, S.E. Babcock, D.S. Stone, Materials Science & Engineering Dept, Ling Zhang and T.F. Kuech, Chemical Engineering Dept, University of Wisconsin-Madison, Madison, WI.

Diffraction-contrast transmission electron microscopy and micro-diffraction techniques were used to uncover and characterize dislocation arrangements a thick (15 μm), coalesced GaN film grown by MOVPE LEO. The windows in the LEO substrate were 1.5 μm wide with a 12 μm spacing and their long axis oriented along the $<1-100>$ direction of underlying GaN on sapphire. Trimethylgallium (TMGa) and ammonia precursors with a V/III ratio of 1800 were used to grow the film in 2 hours at 1100°C. Under these conditions, the cross-section of the growing GaN prior to coalescence is a beveled rectangle with side walls parallel $\{11-20\}$ and bevels on $\{11-21\}$. As is commonly observed, the threading dislocations that are duplicated from the template above the window bend until they lie parallel to the substrate plane and are annihilated at the coalescence plane. The GaN that grows directly above the window has a lower dislocation density as a result. However, new, dense dislocation complexes that appear to originate from the coalescence plane are generated in the top half of the film. Dislocation loops appear to nucleate at the boundary and extend in a very reproducible pattern into the film a distance that is proportional to the distance of from the substrate. These dislocations first appear about 6 μm from the substrate, which is also the thickness by which almost all of the original threading dislocations have bent into the (0001) plane. Sets of loops sweep out an approximately triangular bar shaped volume centered on the plane of coalescence. The result is an increasingly higher dislocation density with distance from the substrate and a complex dislocation arrangement in the thick, coalesced GaN film. This work is supported by the ONR MURI on Compliant Substrates at the University of Wisconsin (UW) -Madison. The NSF-MRSEC at UW provides partial support for the UW electron microscopy facilities.

SESSION O2/L2/II4: JOINT SESSION:
BIAXIALLY TEXTURED SUBSTRATES FOR
HIGH-Tc COATED CONDUCTORS
Chairs: Ron Feenstra and James M.E. Harper
Tuesday Morning, November 30, 1999
Room 200 (H)

8:30 AM *O2.1/L2.1/II4.1

HIGH-J_c, YBCO CONDUCTORS FABRICATED BY EPITAXIAL DEPOSITION OF YBCO ON ROLLING ASSISTED BIAXIALLY TEXTURED SUBSTRATES (RABiTS). A. Goyal, R. Feenstra, M. Paranthaman, F.A. List, D.F. Lee, D.P. Norton, P.M. Martin, D. Verebelyi, X. Cui, E.D. Specht, D.B. Beach, T. Chirayil, C. Park, D.M. Kroeger and D.K. Christen, Oak Ridge National Laboratory, Oak Ridge, TN.

Progress made in the fabrication of Rolling assisted biaxially textured substrates (RABiTS) and epitaxial deposition or formation of HTS on such substrates is reported. Significant progress has been made in the fabrication of non-magnetic, strengthened, biaxially textured metal templates, deposition of oxide and other buffer layers and in the fabrication of long length substrates and superconductors. Ni-Cr alloy substrates fabricated using thermomechanical processing show a single orientation cube texture (~100%) with sharp in-plane and out-of-plane textures, essentially identical to that obtained for pure Ni. High J_c's exceeding 1 MA/cm^2 have been demonstrated on epitaxially grown YBCO films on RABiTS using Ni-Cr as the starting template. Tensile tests and magnetic hysteresis and susceptibility measurements show that the substrates have greatly reduced magnetic properties compared to Ni, and are significantly stronger. In the area of buffer layer development, significant progress has been made in the formation of single orientation oxide buffer layers on Ni using sol-gel processes. A variety of Re_2O_3 type materials have been fabricated in this manner. The buffer layers are dense and crack-free and electron backscatter diffraction patterns show that the films have a high crystalline quality. High J_c's exceeding 1 MA/cm^2 have been demonstrated on such substrates using intermediate vapor deposited buffer layers. Progress made in the area of long length deposition using both vapor deposition and sol-gel will be reported. Efforts are underway to fabricate longer length superconductor samples exceeding l0cm and results obtained will also be summarized.
*Research sponsored by U.S. Department of Energy under contract DE-AC05 96OR22464 to Lockheed Martin Energy Research Corporation.

9:00 AM *O2.2/L2.2/II4.2

INCLINED SUBSTRATE DEPOSITION BY EVAPORATION OF MAGNESIUM OXIDE FOR COATED CONDUCTORS. Markus Bauer, Ralf Metzger, Robert Semerad, Paul Berberich, Helmut Kinder, Technische Universität München, Physik Department, Garching, GERMANY.

Thin films of $YBa_2Cu_3O_7$ (YBCO) must be highly textured in order to have good superconducting properties. One way to achieve this is to grow textured buffer layers on arbitrary polycrystalline substrates by inclined substrate deposition (ISD). This was first proposed by Hasegawa et al. using pulsed laser ablation. We use evaporation techniques to make the ISD process scalable to large areas and high production rates. Buffer layers of MgO are deposited at very high rate either by e-beam or simply by thermal reactive evaporation on substrates of hastelloy or stainless steel inclined by typically 40°. This leads to columnar growth with biaxial texture, improving with thickness up to 2 μm. YBCO films grown on these buffers are highly textured with FWHMs around 8°. The CuO_2 planes of the YBCO are typically tilted with respect to the surface by 20° towards the direction of vapor incidence. Therefore the critical current density is anisotropic, with lower j_c along the vapor direction and twice as much across. This direction must be chosen along the tape for coated conductors. The highest j_c we have reached so far is 0.8 MA/cm^2, resistively measured. To understand the texturing mechanism we have carried out Monte Carlo simulations. These confirm the columnar growth mode. We find that the preferred orientation arises from two effects, namely biased hopping of the particles due to their initial momentum, and mutual shadowing of the colums selecting the fastest growing orientation. Issues of magnetic anisotropy, production rate, upscaling of tape length, and cost will be addressed.

9:30 AM *O2.3/L2.3/II4.3

ION BEAM INDUCED GROWTH STRUCTURE OF FLUORITE TYPE OXIDE FILMS FOR BIAXIALLY TEXTURED HTSC COATED CONDUCTORS. Yasuhiro Iijima, Mariko Kimura, Takashi Saitoh, Fujikura Ltd., Material Technology Lab., Tokyo, JAPAN.

The achievement of sharp biaxial alignment of Yttria Stabilized Zirconia (YSZ) films by off-normal ion-beam-assisted deposition (IBAD) produced a hopeful application as flexible HTSC coated conductors using metallic substrates. Quite high-J_c values were successfully achieved by removal of intergranular weaklinks in Y-123 films on the YSZ templates. Till now 2-3 m length Y-123 tapes were fabricated using random polycrystalline Ni-based alloy tapes coated with textured YSZ layers. Ar^+ ion bombardment had significant effects on the crystalline structure of the YSZ films; to align a $< 100 >$ axis with the substrate normal, and a $< 111 >$ axis with the bombarding beam axis. Those two effects were induced simultaneously at room temperature and resulted in peculiar biaxially textured structure without epitaxial relationship to substrates. This paper discuss the alignment mechanism with the structural properties of several fluorite or related type oxide films including YSZ, CeO_2, Y_2O_3, etc., based on several proposed models. Films were formed on polycrystalline Ni-based alloy by dual ion beam sputtering method. Growth structures were characterized by X-ray diffraction (XRD), transmission electron microscopy (TEM), atomic force microscopy (AFM) etc. Peculiar structural evolution of the crystalline orientation was observed and its development was well described by an exponential equation which agreed with Bradley's selective growth model. It could be explained as a collaboration among in-plane and out-of-plane anisotropic growth of surface crystallites, and also homoepitaxial growth onto crystalline surface beneath, both induced by Ar^+ ion bombardment. Very smooth surfaces were observed by AFM imaging with a roughness of 2-3 nm and a peculiar ripple structure. The surface topographic structure was discussed by relating to Ressler's surface binding energy model without using ion channeling. Because the energy of assisting ions were too low as 200 - 300 eV, the origin of azimuthal aligning effect is still under controversy.

10:30 AM *O2.4/L2.4/II4.4

BIAXIALLY TEXTURED BUFFER LAYERS ON LARGE-AREA POLYCRYSTALLINE SUBSTRATES. H.C. Freyhardt[1,2], J. Dzick[1,3], S. Sievers[1,3], J. Hoffmann[1], K. Thiele[1], F. Garcia-Moreno[1,2], A. Usoskin[2] and Ch. Joss[1]; [1]Institut fuer Materialphysik, Universitaet Goettingen, Goettingen, GERMANY, [2]ZFW: Zentrum fuer Funktionswerkstoffe GmbH, Goettingen, GERMANY, [3]Kabelmetal Electro GmbH, Hannover, GERMANY.

Biaxially textured buffer layers on polycrystalline metallic or ceramic substrates are required as templates for high-current-carrying HTS films, particularly coated YBCO films. In this contribution we report on our present understanding of the mechanisms governing the ion-beam-assisted deposition (IBAD) process employed for the preparation of textured YSZ as well as CeO_2 and Gd-doped CeO_2. On Ni, Hastelloy, SS as well as on ceramic tapes IBAD buffers could be produced with high-quality in-plane textures characterized by a FWHM of considerably smaller than 20°. Two systems were used, one with two 11 cm sputter sources and a 21 cm Kaufman ion source for the assisting beam and a second one with 11 cm sources for sputtering and the assisting beam. Furthermore, the IBAD process is now developed to an extend to allow the coating of large-area substrates (up to 20 cm x 50 cm) with well textured buffer films. Maximum current densities of PLD-YBCO layers on IBAD-buffered substrates reach values up to 2 MA/cm^2.
In parts supported by the German BMBF, kabelmetal electro GmbH and Siemens AG under grants 13 N 6924/6 and 13 N 6482, respectively.

11:00 AM *O2.5/L2.5/II4.5

METHODS EMPLOYED FOR PRODUCING HIGH-QUALITY ION-BEAM DEPOSITED CUBIC OXIDE TEMPLATE FILMS ON METAL SUBSTRATES. P.N. Arendt, J.R. Groves, S.R. Foltyn, Q.X. Jia, H.H. Kung, T.G. Holesinger, E.J. Peterson, P.C. Yashir, M.R. Fitzsimmons, R.F. DePaula, J.Y. Coulter, Y. Fan and M. Ma, Los Alamos National Laboratory, Los Alamos, NM.

Ion-beam assisted deposition was used to fabricate biaxially aligned cubic zirconia or magnesia films on flexible metal substrates. These films are used as templates for heteroepitaxially deposited YBCO films. The quality of the crystalline texture of the template films has a direct influence on the superconducting properties of the final YBCO films. We describe our efforts to fabricate high-quality templates on small-area substrates processed in stationary mode and meter-long substrates processed in continuous mode. Cubic zirconia templates were deposited on the meter-long substrates and magnesia templates were deposited on the small-area substrates. Our best phi scan FWHM values for the films on the meter-long tapes are 12.6 degrees for the template and 6.1 degrees for the overcoated YBCO. This meter-long tape had self-field, 75 K, superconducting critical current of 122 amps. Our best phi scan FWHM values for the films on small area substrates are 5.6 degrees for the template and 3.6 degrees for the overcoated YBCO. We will also describe x-ray grazing incidence measurements of the topmost layers of the template films as well as TEM measurements of the film microstructure.

11:30 AM O2.6/L2.6/II4.6
LEVEL SET SIMULATION OF ION BEAM ORIENTED MgO GROWTH. Xingquan Li, Dept. of Physics, University of Michigan, Ann Arbor, MI; Peter S. Smereka, Dept. of Mathematics, University of Michigan, Ann Arbor, MI; David J. Srolovitz, Princeton Materials Institute, Princeton University, Princeton, NJ; Giovanni Russo, Dept. of Mathematics, University of L'aquila, L'aquila, ITALY.

We have developed a general purpose algorithm for the growth of faceted thin films from the vapor based upon the level set method. In the present simulations, we focus on the growth of polycrystalline MgO from the vapor in the presence of a low energy ion beam, which is used to establish in-plane texture. While out-of-plane texture {100} forms naturally, the ion beam selects grains which are oriented in a channeling direction with respect to the oblique beam. Growth rates of individual grains vary with grain orientation. We determine the polycrystalline microstructure, grain size and the width of the orientation distribution as a function of ion beam properties.

11:45 AM O2.7/L2.7/II4.7
QUANTITATIVE RHEED ANALYSIS OF BIAXIALLY-TEXTURED POLYCRYSTALLINE MgO FILMS ON AMORPHOUS SUBSTRATES GROWN BY ION BEAM-ASSISTED DEPOSITION. R.T. Brewer, J.W. Hartman and Harry A. Atwater, California Institute of Technology, Dept of Applied Physics, Pasadena, CA.

We have developed a computer simulation based on analytic calculation of RHEED patterns in the kinematic approximation for mosaic polycrystalline films for given values of electron beam incidence angle, polycrystalline texture, in-plane orientation distribution, and grain size. Although RHEED is most accurately modeled using a dynamical scattering model, the computational efficiency of kinematical scattering lends itself to development of a model suitable for real time control of biaxially-textured film growth by ion beam-assisted deposition (IBAD). Using the simulation results, we can quantitatively determine how RHEED spot shapes and relative intensities depend on the mosaic film characteristics. RHEED patterns taken at 15 keV with incidence angle in the range 1-5 degrees from 10 nm thick nominally [100]-textured MgO films grown on amorphous Si_3N_4 films by IBAD were analyzed by comparing experimental RHEED spot shapes and relative intensities with those predicted by the simulation results. For some films, an additional 200 nm thermally-grown MgO homoepitaxial layer was grown on top of the IBAD MgO layer. Results are also compared to X-ray rocking curve film analysis, and the quantitative correlation between biaxial texture and model-based RHEED analysis will be discussed.

SESSION O3: SURFACES FOR OXIDE EPITAXY
Chair: Darrell G. Schlom
Tuesday Afternoon, November 30, 1999
Harvard (M)

1:30 PM *O3.1
ATOMIC-SCALE CONTROL OF SUBSTRATE SURFACE/ TERMINATION AND HETERO-EPITAXIAL GROWTH. Mamoru Yoshimoto, Tokyo Inst. of Tech., Mater. & Structures Lab., Yokohama, JAPAN.

Atomic-scale control and analysis of surface/termination of single-crystal oxide substrates were performed by thermal processing and characterization via RHEED, CAICISS (Coaxial Impact Collision Ion Scattering Spectroscopy) and AFM. CAICISS enabled us to determine the terminating atomic species and their arrangements of oxide substrates and epitaxial oxide films. The atomic-scale substrate engineering made it possible to attain the novel heteroepitaxial growth such as room-temperature epitaxy of oxide on Si, step-flow epitaxy leading to the nano-structure formation and diamond epitaxy on sapphire. On the single crystal substrates with atomically flat terrace and step structures, the two-dimensional nucleation followed by molecular layer-by-layer growth was verified by in situ monitoring of RHEED intensity oscillation as well as AFM observation. The high-quality epitaxial diamond films could be grown on atomically flat sapphire substrates at the temperatures lower than 600°C by pulsed laser ablation of graphite in an oxidizing environment. The present work also demonstrates the advanced oxide thin film processing based on laser MBE to control the growth and surface of films on an atomic scale.

2:00 PM O3.2
CRYSTAL GROWTH MECHANISM OF METAL OXIDE ELECTRONICS MATERIALS: THEORETICAL SIMULATION STUDY. Momoji Kubo, Yusaku Inaba, Takayuki Onozu, Seiichi Takami, Akira Miyamoto, Tohoku Univ., Dept. of Materials Chemistry, JAPAN; Masashi Kawasaki, Tokyo Inst. of Technol., Interdisciplinary Graduate School of Eng., Yokohama, JAPAN; Mamoru Yoshimoto, Tokyo Inst. of Technol., Materials and Structures Lab., Yokohama, JAPAN; Hideomi Koinuma, Tokyo Inst. of Technol. and CREST-JST, Materials and Structures Lab., Yokohama, JAPAN.

Novel technology on the artificial construction of atomically defined metal oxide layers has been desired in relation to electronic, magnetic, and optical devices. Hence, the atomistic understanding of the epitaxial growth processes of metal oxide surfaces is desired to fabricate atomically controlled structure that exhibits unexplored and interesting physical properties. However, experimentally it is impossible to clarify the atomistic mechanism of epitaxial growth process of metal oxide electoronics materials. Although theoretical simulations has been desired to elucidate the above mechanism, there were no molecular dynamics simulations on the epitaxial growth process of metal oxides. Hence, we developed a new atomistic crystal growth simulator MOMODY[1] and applied it to the homoepitaxial growth processes of MgO(001), $SrTiO_3$(001), ZnO(0001), and ZSM-5(010) surfaces [1-4]. Especially, the effect of substrate temperature and the surface morphology on the epitaxial growth were clarified. Some results are in good agreement with the experimental results, and various new findings were obtained. Moreover, the heteroepitaxial growth processes of BaO/$SrTiO_3$(001), MgO/sapphire(0001), and so on were investigated. We reproduced various crystal growth processes such as Frank-van der Merve mode, Volmer-Weber mode, and Stranski- Krastanov mode. We discussed what determine the crystal growth mode of metal oxides in the presentation.

[1] M. Kubo, Y. Oumi R. Miura, A. Stirling, A. Miyamoto, M. Kawasaki, M. Yoshimoto, and H. Koinuma, Phys. Rev. B 56 (1997) 13535.
[2] M. Kubo, Y. Oumi R. Miura, A. Stirling, A. Miyamoto, M. Kawasaki, M. Yoshimoto, and H. Koinuma, J. Chem. Phys. 109 (1998) 8601.
[3] M. Kubo, Y. Oumi R. Miura, A. Stirling, A. Miyamoto, M. Kawasaki, M. Yoshimoto, and H. Koinuma, J. Chem. Phys. 109 (1998) 9148.
[4] M. Kubo, Y. Oumi, H. Takaba, A. Chatterjee, and A. Miyamoto, J. Phys. Chem. B 103 (1999) 1876.

2:15 PM O3.3
GROWTH AND STRUCTURAL CHARACTERIZATION OF Sr_2TiO_4: CHEMICAL CONTROL OVER THE TERMINATING $SrTiO_3$ SURFACE. P.A. Salvador, Carnegie Mellon University, Department of Materials Science and Engineering, Pittsburgh, PA; B. Mercey, O. Perez, A.M. Haghiri-Gosnet, T.-D. Doan, B. Raveau, Laboratoire CRISMAT-ISMRA, Caen, FRANCE.

In an effort to achieve facile in-situ control over the terminating surface of (100)-oriented $SrTiO_3$ single crystals, we investigated the growth of Sr_2TiO_4. Single, half unit-cell Sr_2TiO_4 monolayers deposited over TiO_2-terminated $SrTiO_3$-surfaces can be viewed as homoepitaxial $SrTiO_3$ layers (1.5 unit cells thick) having SrO-terminated surfaces. Thin films of Sr_2TiO_4 were grown using pulsed laser deposition (PLD) and laser-MBE on $SrTiO_3$ (100)-oriented single crystal substrates. Films were characterized by X-ray diffraction (XRD), X-ray reflectometry, electron diffraction, and atomic force microscopy. Films grown by PLD in high-oxygen pressure environments display only a single peak in the XRD spectra, corresponding to the (006) peak of the K_2NiF_4 parent structure. The absence of lower-order peaks is discussed with respect to a loss of long-range order in this high growth rate technique. Using a Laser-MBE deposition technique in lower oxygen pressure allows for in-situ monitoring of the growth using RHEED. Two-dimensional growth and RHEED intensity oscillations can be routinely obtained. The period of the intensity oscillations was confirmed to correspond to the deposition of a complete-layer of the smallest charge-neutral structural entity: one-half the unit cell. In contrast to PLD-grown films, the (004) peak is observed in XRD spectra for the Laser-MBE-grown films. This is discussed and modeled with respect to in-plane disorder arising from substrate step-edges and out-of-plane film-substrate structural mismatches. That a single, half unit-cell can be deposited allows one to flip the terminating surface of $SrTiO_3$ in a controlled and simple manner from a pure TiO_2 layer to a SrO layer. Experimental evidence of the importance of such surface control is given for the $SrCuO_2$ structural stability.

3:00 PM *O3.4
INTERFACIAL STRUCTURE OF COMMENSURATE CRYSTALLINE OXIDES ON SEMICONDUCTORS. M.F. Chisholm, F.J. Walker and R.A. McKee, Oak Ridge National Laboratory, Oak Ridge, TN.

The promise of a new generation of advanced microdevices has sparked considerable effort in the growth of oxide films on silicon. Unfortunately, there is a strong propensity for reactions between these materials[1]. The formation of undesirable phases at the oxide/semiconductor interface adversely affects the integrated functionality of these materials. Our aim has been to understand and control the layer-by-layer growth sequence in order to bring the crystalline oxides into intimate physical and electrical contact with the semiconductor[ii]. We report microstructural characterization of perovskite/semiconductor interfaces as evidence that the layering sequence does indeed control interface stability. The images show that a growth sequence exists that allows the deposition of alkaline earth and perovskite oxides on silicon without the formation of interfacial misfit dislocations or silicon oxides. We demonstrate that the resulting near ideal physical structure of the interface couples directly to its electrical structure and provides the low interface trap density required in hybrid microdevices.

[i]K.J. Hubbard and D.G. Schlom, J. Mater. Res. 11, 2757 (1996).

[ii]R.A. McKee, F.J. Walker and M.F. Chisholm, Phys. Rev. Lett. 81, 3014 (1998).

Research sponsored by the Division of Materials Science, U.S.Department of Energy under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corporation.

3:30 PM O3.5
ATOMIC LAYER CONTROL OF EPITAXIAL $SrRuO_3$ THIN FILMS ON BOTH TiO_2- and SrO-TERMINATED (001) $SrTiO_3$ SUBSTRATES BY HIGH PRESSURE RHEED. J.H. Choi, C.B. Eom, Duke University, Department of Mechanical Engineering and Materials Science, Durham, NC; A.J.H.M. Rijnders, F.J.G. Roesthuis, D.H.A. Blank, Department of Applied Physics, University of Twente, Enschede, THE NETHERLANDS; J.C. Jiang, X. Pan, University of Michigan, Department of Materials Science and Engineering, Ann Arbor, MI.

Single atomic layer terminated $SrTiO_3$ substrate is an ideal system to study the heteroepitaxial growth mechanism of various perovskite thin films and to fabricate high quality multilayered devices. Single crystal epitaxial thin films of $SrRuO_3$ has been used as a model system. $SrRuO_3$ is a pseudo-cubic perovskite with a lattice parameter of 3.93 Å , i.e., a lattice mismatch with (001) $SrTiO_3$ substrates of 0.64%. We have investigated the stacking sequence of $SrRuO_3$ films grown on both well-defined TiO_2- and SrO-terminated $SrTiO_3$ substrates using pulsed laser deposition with high pressure reflected high energy electron diffraction (RHEED). TiO_2-terminated (001) $SrTiO_3$ substrates were obtained by a three-step treatment: soak in water, chemical etching with a BHF solution, followed by post-annealing at 950°C for 1 h. On the other hand, SrO-terminated $SrTiO_3$ substrates were prepared by depositing one monolayer of SrO on a TiO_2-terminated $SrTiO_3$ substrate. RHEED intensity has been used for monitoring the thickness. AFM studies revealed that the surface morphology of the $SrRuO_3$ films on both substrates is extremely smooth with only steps of one-unit cell height, without any step bunching. No half unit cell steps are observed. From our RHEED intensity data we conclude that the $SrRuO_3$ films grow in a step-flow mode. We will discuss the influence of the termination of the $SrTiO_3$ substrate on the termination of the topmost layer of the $SrRuO_3$ thin films studied by high-resolution transmission electron microscopy. In addition, a detail stacking sequence of the $SrTiO_3/SrRuO_3/SrTiO_3$ trilayer structure will also be discussed in relation to the surface termination.

3:45 PM *O3.6
CONROLLED TERMINATION OF LAYERED OXIDES BY CHEMICAL TREATMENTS. Dave H.A. Blank, Univ. of Twente, Applied Physics Dept., Enschede, THE NETHERLANDS.

Substrates with atomically flat surface are a prerequisite to obtain well-defined thin films. In the case of substrates that consist of multiple elements, like the perovskites $SrTiO_3$, $LaAlO_3$, LSAT, $NdGaO_3$, a flat surface is not enough. The epitaxial growth will be influenced by the termination of the substrate. Important becomes the mis-cut angle of the substrate and the way it has been treated during polishing. In order to obtain high quality substrates, Kawasaki et al.[1] suggested the use of buffered HF. Afterwards, Koster et al.[2] showed the effect of pre-treatment in the case of $SrTiO_3$.
In this contribution the effect of different etchants (NH_4F HF, NH_4Cl HCl, HCl, and *aqua regia*) with various pH values will be shown. From Atomic Force Microscopy (in air) we conclude that, in the case of $SrTiO_3$ (001) substrates, irrespective of the etchant that has been used, TiO_2 terminated $SrTiO_3$ surfaces atomically flat terraces without etch pits could be obtained. The pH-value and temperature of the etchant and the etching time, however, influences the surface quality significantly. Reflected high energy diffraction patterns confirmed the AFM results. The same procedure has been applied to different other perovskite substrates, like $LaAlO_3$ and LSAT. In this contribution an overview will be given about the latest results.

[1] Kawasaki et al. Science 226, 1540 (1994)
[2] Koster et al. Appl. Phys. Lett. 73, 2920 (1998)

4:15 PM O3.7
EPITAXIAL ELECTRONIC OXIDES ON SEMICONDUCTORS USING PULSED-LASER DEPOSITION. David P. Norton, John. D. Budai, Matthew. F. Chisholm, Gerald. E. Jellison, Jr., and Yong E. Lee, Oak Ridge National Laboratory, Oak Ridge, TN.

The integration of electronic oxides with semiconductors continues to be an important area of materials research. Recent progress in the epitaxial growth of oxides on elemental and compound semiconductors bears the promise of incorporating ferroelectric, magnetoresistive, or high-k dielectric materials into existing integrated semiconductor platforms. For most of these applications, the structure of the interface and crystalline quality of the film directly impacts the performance of the device. In this talk, we will discuss recent results on the epitaxial growth of oxide materials on single crystal elemental and compound semiconductor substrates using pulsed-laser deposition. Reflection high energy electron diffraction is used to characterize the initial state of the semiconductor surface, as well as to elucidate the initial sequences involved in epitaxy of the oxide on the semiconductor. Scanning transmission electron microscopy is used to atomically resolve the structure at the semiconductor/oxide interface. Atomic force microscopy is used to understand the mechanisms of film growth and morphology development. The electronic and optical properties of the oxide films will also be reported. This research was sponsored by the Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corp., for the U.S. Department of Energy, under contract DE-AC05-96OR22464.

4:30 PM O3.8
EPITAXIAL CERAMIC FILMS ON METAL SUBSTRATES. Mani Gopal, Michael J. Cima, Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA.

For several applications, it is necessary to grow epitaxial layers of oxide ceramics on metal substrates. These oxide layers can either be the active layer (e.g., dielectrics), or can act as a buffer layer on which the active layer is grown (e.g., superconductors). The growth of epitaxial oxide layers on metals that can oxidize is difficult because the oxide scales are usually polycrystalline or amorphous. This layer acts as a barrier and prevents the formation of epitaxial films. The oxide layer must be removed in situ, prior to the deposition of the oxide film to obtain epitaxy. We have developed a method of growing epitaxial oxide layers (Y_2O_3, YSZ, CeO_2) by electron beam evaporation of oxide sources onto nickel substrates. The experimental requirement is that the oxygen in the vacuum chamber be as low as possible. To achieve this, the source material is heated using the electron beam in a reducing atmosphere (hydrogen gas). This process reduces the ceramic, making it deficient in oxygen. Following this, the substrate is heated to 600-700°C in hydrogen. This process not only removes the nickel oxide, but also induces surface recrystallization removing any structural defects. Subsequently, the oxide layer is deposited on the metal. The microstructure and crystallinity of the buffer layer is characterized as a function of the processing condition. Ongoing work is being directed towards the use of oxide films as buffers for growth of superconducting thin films.

SESSION O4: WAFER BONDING AND LIFT-OFF

Chairs: Tony E. Haynes and David P. Norton
Wednesday Morning, December 1, 1999
Harvard (M)

8:30 AM *O4.1
SUBSTRATE ENGINEERING BY WAFER BONDING: ISSUES AND CHALLENGES. U. Gösele, St. Senz, G. Kästner, P. Kopperschmidt, M. Alexe, and A. Ploessl, Max-Planck-Institute of Microstructure Physics, Halle, GERMANY.

Wafer bonding allows to transfer layers of a single crystalline material onto an appropriate substrate which might differ from the crystalline layer in terms of orientation, material or crystallinity. Therefore, new and highly desirable materials combinations may be fabricated for further epitaxial growth on the transferred single crystalline layer. After first discussing general issues in the area of wafer bonding, the talk will touch more specifically on hydrogen-implantation induced thin layer transfer ('smart cut' and 'smarter-cut'). Specific examples of InP-on-silicon, silicon-on-quartz, GaAs-on-silicon and silicon-on-GaAs will be given. A wafer bonding approach to produce a highly carbon-doped silicon film for the epitaxial growth of diamond will be presented. Whether "universal compliant substrates" fabricated by twist wafer bonding are fact or fiction will also be discussed in some detail.

9:15 AM O4.2
Si/SiC UHV DIRECT WAFER BONDED INTERFACE STRUCTURE. M.J. Kim, H. Xu, R.-J. Liu and R.W. Carpenter, Arizona State University, Center for Solid State Science, Science and Engineering of Materials, Tempe, AZ.

We have examined the structure of Si/SiC UHV direct wafer bonded interfaces to determine the structure in the absence of oxygen. The (100) Si and (0001) SiC wafers were HF cleaned before insertion in the bonding system and then thermally desorbed at 1,100°C before bonding at 1,100°C for 5 hours under 1 MPa pressure. The SiC wafer used was vicinal, with about 3.5° surface normal tilt toward [11$\bar{2}$0]. The Si terminated surface was used for bonding, but the desorption process caused this surface to become slightly carbon rich before bonding. Electron microscopy showed the wafers to be directly crystal to crystal bonded over essentially their entire surfaces. There was no amorphous layer at the interface, such as one might expect in the presence of surface oxide layers. A few discrete voids were observed extending to one side of the interface or the other, but not both. Those extending into the SiC are understandable in terms of the initial surface roughness, which was determined by AFM. The Si wafer was quite flat, however, and there is currently no explanation for the few voids that extend into the Si. A low density of dislocation half loops extends from the interface into the Si. We believe these are due to surface contact stress concentrations where the SiC made point contact with the Si wafer. At the interface itself there are contrast variations indicating that additional disorder may be present, but these can also be associated with variations in electron optical conditions. The interface appears to be much stronger than either SiO_2/SiC or SiC/SiC direct bonded interfaces. Our object here is a description of the interface structure as a function of synthesis conditions. This research was supported by the Division of Materials Sciences, USDOE, under grant No. DE-FG03-94ER45510.

9:30 AM O4.3
GAS PHASE SURFACE CONDITIONING FOR HYDROPHOBIC SILICON WAFER BONDING APPLICATIONS. James B. Mattzela, Paul A. Roman, Jerzy Ruzyllo, Theresa S. Mayer, The Pennsylvania State University, Department of Electrical Engineering, University Park, PA.

Hydrophobic silicon wafer bonding has been proposed for use in the fabrication of novel dual-sided silicon power devices because of the high-quality electrical interface it produces. Until recently, however, hydrophobic silicon surfaces used for wafer bonding applications were prepared using wet chemical processing, which consists of an RCA clean followed by a dilute HF dip. In this talk, we will discuss the use of dry (gas phase) surface conditioning chemistries as a final conditioning step prior to silicon wafer bonding. Dry phase processing has several advantages over current wet procedures including decreased chemical consumption, reduced contact between personnel and wafers, and compatibility with a "cluster tool" environment. In addition, the surface termination left by gas phase processing is more controllable and more reproducible than that obtained on wet processed surfaces. The quality of hydrophobic silicon wafer bonds was investigated by comparing the bond strength obtained on samples prepared using wet and dry chemistries. The dry processed wafer pairs were cleaned by SC1 to remove particulate contamination prior to loading into a commercially available dry cleaning module. Once loaded, the dry cleaning procedure consisted of anhydrous HF etch to remove the native oxides remaining on the silicon surface followed by a "rinse" in gaseous methanol. Following the dry process, room temperature bonding was performed and the samples were annealed at temperatures ranging from 110°C to 1100°C in N_2 for 2.5 hours to strengthen the bonded interface. Using a crack test, it was determined that wet and dry processed wafers had comparable surface energies for all temperatures investigated. This suggests that gas phase surface conditioning is a viable alternative to wet cleaning chemistries for preparation of silicon surfaces used in hydrophobic wafer bonding.

10:15 AM *O4.4
MECHANISTIC STUDIES OF WAFER BONDING AND THIN SILICON FILM EXFOLIATION. Yves J. Chabal, M.K. Weldon and E. Isaacs, Bell Labs, Lucent Technologies, Murray Hill, NJ.

Wafer bonding presents an interesting alternative to epitaxy. Furthermore, with the development of the SmartCut technique, it is now possible to deposit extremely thin (500$\AA$) crystalline films of some semiconductor materials on many substrates. We address here the mechanisms involved in both wafer bonding and exfoliation by H-implantation (SmartCut process). With IR spectroscopy, we study the chemical evolution of bonded and H-implanted interfaces as a function of temperature. The mechanism for chemical bond formation between two interfaces can be inferred for both hydrophylic (oxidized) and hydrophobic (H-terminated) silicon surfaces in direct Si-Si wafer bonding. The mechanism for shearing Si can also be understood as an evolution of H point defects into H-stabilized internal surfaces, along with molecular H_2 formation. With X-ray microbeam techniques, we are able to image, upon annealing of H-implanted Si, the nucleation and propagation of microbubbles that nucleate prior to exfoliation. In addition, we have used x-ray microdiffraction with 0.5 μm resolution to make a detailed strain map of a bubble just prior to exfoliation, finding that the maximum strain is relatively small (~0.05 %). We are now combining the two techniques to understand the dynamics of cracking in silicon.

10:45 AM *O4.5
INTEGRATION OF EPITAXIAL HETEROSTRUCTURES BY LASER LIFT OFF. T. Sands, W.S. Wong and L. Tsakalakos, Department of Materials Science & Mineral Engineering, University of California, Berkeley, CA; N.W. Cheung, Department of Electrical Engineering & Computer Science, University of California, Berkeley, CA.

The functionality of integrated microsystems can be enhanced through intimate integration of disparate classes of materials. Combining the best materials for their respective functions (e.g., information processing, light emission/detection, and piezoelectric actuation) without sacrificing materials properties is often only possible if the materials are synthesized and processed separately and subsequently combined. In this talk, a fast and simple method for accomplishing this final integration step is described. This laser liftoff (LLO) approach permits separation of epitaxial GaN and perovskite oxide (e.g. PZT) films and heterostructures from their sapphire or magnesia growth substrates, enabling integration of these materials with silicon, glass and polymers without sacrificing properties. The LLO method achieves selective decomposition of a thin interfacial layer by irradiating the absorbing thin film through the transparent substrate with a single nanosecond timescale pulse from an ultraviolet laser, typically a KrF excimer at 248 nm. At this emission wavelength, a pulse length of ~40 ns, and a fluence of 500-600 mJ/cm^2, approximately 50 nm of GaN at the interface with sapphire is decomposed to liquid Ga and N_2 gas. The substrate can then be removed by subsequent heating to above 30°C. This process has recently been applied to the transfer of (In,Ga)N light-emitting-diode heterostructures from sapphire to silicon without altering the electroluminescence spectrum. Epitaxial perovskite oxide films such as $Pb(Zr,Ti)O_3$ can also be separated from sapphire by LLO, however the substrate is ejected during the pulse by the vapor burst and/or the thermomechanical shock wave. The thermal, optical and mechanical aspects of the LLO process, as well as the application of LLO to the fabrication of integrated sensors, actuators and optoelectronic devices will be discussed.

11:15 AM O4.6
LOW TEMPERATURE BONDING OF CERAMICS BY SOL-GEL PROCESSING. C.J. Barbè, D.J. Cassidy, G. Triani, B.A. Latella, D.R. Mitchell, P. Evans, K.S. Finnie, E. Drabarek, Z. Zhang, K. Short, J.R. Bartlett, J.L. Woolfrey and G. Collins, Materials Division, ANSTO, Menai NSW, AUSTRALIA.

Traditional methods for bonding ceramics involve either the use of direct bonding at temperatures exceeding 1000°C, or polymers. However, the former approach is incompatible with the packaging requirements of modern electronic components, while the latter approach yields interfaces with significant permeability to chemical vapours and gases. These limitations are overcome by sol-gel processing, which enables strong, low-permeability ceramic-ceramic bonds to be produced at low temperature. Sol-gel bonds were produced between clean, smooth substrates (silicon, silica, sapphire, or polycrystalline alumina) by spin-coating solutions containing partially-hydrolysed silicon alkoxides onto both wafers. The two coated-substrates were then assembled and the resulting sandwich fired at temperatures ranging from 300 to 600°C. The influence of the substrate surface chemistry and sol-gel process chemistry on the microstructure and fracture toughness of the interfacial layers was investigated using a wide range of techniques, including ellipsometry, FTIR, N_2 adsorption (in conjunction with a SAW device), SEM, TEM, AFM, XPS, SIMS and indentation methods. The interfacial layers between bonded silicon wafers were smooth, 20-50 nm thick, and dense ($<$ 5% porosity), with significantly higher fracture energies (2.5 to 5 J m^{-2}) than those obtained previously using classical water bonding or sol-gel bonding (1.25 and 1.75 J m^{-2}, respectively). Polycrystalline alumina substrates were similarly bonded at 300 to 600°C. However, in this latter case, the sol-gel chemistry was optimised to produce thicker (up to 1 mm), stress-free interfacial layers. These optimised sol-gel coatings yielded interfaces with fracture energies of ca. 4 J m^{-2}.

11:30 AM O4.7
LOW-PRESSURE CHEMICAL VAPOR DEPOSITION OF BOROSILICATE GLASSES AND APPLICATION TO BONDED AND COMPLIANT SUBSTRATES. D.M. Hansen, P.D. Moran and T.F. Kuech, University of Wisconsin-Madison, Department of Chemical Engineering, Madison, WI.

Borosilicate glasses (BSGs) possess many properties that are desirable for use in compliant and wafer-bonded substrate technologies. The essential features of the deposition process and the film properties are presented here in the context of their use as an alternative to pure silica. BSGs possess a composition dependent viscosity and thermal expansion coefficient, which can be matched to that of common semiconductors. We have investigated the growth, properties and morphology of chemical vapor deposited BSGs for use in these applications. The BSG films were deposited in a conventional low-pressure chemical vapor deposition reactor typically operating at 1 Torr and 675C using tetraethylorthosilicate (TEOS) and trimethylborate (TMB) as the growth precursors. This chemical system allows for the deposition of all compositions of BSG from pure silica to boron oxide. While the deposition of silicon dioxide is a well-studied system, the deposition of boron-doped films is less understood. The deposition of silica from TEOS followed previously observed kinetic trends. The deposition rate of the silica mole fraction in the films was accelerated by the presence of TMB and oxygen. The gas phase processes involved in these cooperative deposition processes was studied by mass spectroscopy in an isothermal reactor under gas phase transport conditions similar to the deposition system. Typically, the BSG films have a rms roughness on the order of 0.5 nm as measured by atomic force microscopy. Annealing the films at high temperature (>650C) reduces the film roughness through glass reflow, a process which increases with boron content where the initial film roughness is higher. The chemistry occurring at the bonded interface is also important. Preliminary investigations into the nature of the BSG layer bonded interface using infrared spectroscopy will be presented. The role of surface hydroxyl groups, important in bonding of hydrophilic interfaces, in binding BSG-to-BSG will be discussed.

SESSION O5: LATTICE MISMATCH ENGINEERING I

Chair: Ulrich M. Goesele
Wednesday Afternoon, December 1, 1999
Harvard (M)

1:30 PM *O5.1
STRESS-ENGINEERED SUBSTRATES FOR HETEROEPITAXIAL GROWTH. Yu-Hwa Lo Cornell University, Ithaca, NY.

Substrate engineering can help heteroepitaxial growth by applying the "right" amount of stress in the "right" sense to the heteroepitaxial layer to confine dislocations from propagation. The first challenge is how to make the substrate stable over a wide range of temperature while applying stress to the epitaxial layer. The second challenge is how to assure that the dislocations in the heteroepitaxial layer gains enough mobility to react with the stress field. In general, low yield stress and high dislocation velocity help the dislocation confinement process, and high temperature is in favor of both. However, for any given material there is always a temperature limit that the epitaxial material can take and the growth can take place. This temperature limit may not always fall in the temperature range for effective dislocation confinement. This presentation will talk about the principle, design, and technology of stress-engineered substrates and the results of heteroepitaxial growth on such substrates.

2:15 PM O5.2
DEPENDENCE OF FILM RELAXATION ON FILM MISMATCH AND THICKNESS IN InGaAs ON GLASS-BONDED GaAs COMPLIANT SUBSTRATES. P.D. Moran, D.M. Hansen and T.F. Kuech, University of Wisconsin-Madison, Department of Chemical Engineering, Madison, WI.

The ability of compliant substrates to modify the relaxation behavior of subsequently grown mismatched films has been demonstrated. The compliant substrates consisted of <10nm thick GaAs growth template bonded to a CVD-borosilicate glass layer on a GaAs mechanical handle wafer. The breadth of high resolution x-ray diffraction (HRXD) peaks from 3 μm thick highly mismatched InGaAs(40% In) films grown on these substrates is significantly narrower than for films grown simultaneously on conventional substrates. The position of the HRXD peak from 3 μm of slightly mismatched InGaAs(1%In) films grown on compliant substrates differs from that of the film simultaneously grown on the conventional substrate, indicating an enhancement of relaxation due to growth on the compliant substrates. It has been proposed that the relaxation of films grown on compliant substrates can be understood through considering an elastic partitioning of strain between the film and the growth template considered as a free-standing thin substrate. This assumption leads to quantitative predictions of the strain state of films grown to less than the critical thickness for the system as a function of template thickness, film thickness, and film mismatch. HRXD measurements of the strain state of ~100nm InGaAs (3% In) films and InGaAs(9%In) films grown simultaneously on conventional and glass-bonded GaAs substrates have been performed. The results of these experiments are discussed in terms of the prediction of the strain state of films grown on free-standing thin substrates.

2:30 PM O5.3
EFFECTS OF SUBSTRATE THICKNESS AND COMPOSITIONAL GRADING ON INTERFACIAL STABILITY AND STRAIN RELAXATION KINETICS IN LAYER-BY-LAYER SEMICONDUCTOR HETEROEPITAXY. L.A. Zepeda-Ruiz, R.I. Pelzel, B.Z. Nosho, W.H. Weinberg, and D. Maroudas, Department of Chemical Engineering, University of California, Santa Barbara, CA.

Outstanding questions in the area of semiconductor heteroepitaxy involve mechanisms of strain relaxation, such as the formation of interfacial misfit dislocations and surface morphological transitions. The corresponding rates of strain relaxation can be affected significantly by using thin compliant substrates instead of thick rigid substrates. Additional effects on the strain relaxation can be induced by grading simultaneously the chemical composition of the grown films. We present a comprehensive thoretical study of interfacial stability with respect to misfit dislocation formation, of film surface morphology, and of strain relaxation kinetics for epitaxial growth of InAs on GaAs(111)A, where the growth mode remains always layer-by-layer. In our analysis, the substrate thickness is used as a parameter, thus addressing the effects of using thin compliant substrates in heteroepitaxy. In addition, a heteroepitaxial system is analyzed that contains one monolayer of $In_{0.5}Ga_{0.5}As$ between the GaAs substrate and the InAs film, to address the simultaneous effects of compositional grading on strain relaxation. Our interfacial stability analysis combines continuum elasticity theory with atomistic simulations of the energetics and relaxed structures of heteroepitaxial film/sustrate sytems based on a valence force field description of the interatomic interactions. The kinetic analysis is based on a phenomenological mean-field theoretical framework for the dynamics of strain relaxation due to formation of threading dislocations in the film and interfacial misfit dislocations. The energetics of the coherent-to-semicoherent interface transition and the corresponding critical film thicknesses are predicted and the structures of the semicoherent interfaces containing networks of misfit dislocations are characterized in detail. The computed film surface morphology also is presented as a function of film thickness. Furthermore, the evolution of strain relaxation in the film is computed as a function of substrate thickness and compositional grading. All of our theoretical results are compared with experimental measurements of $InAs/In_{0.5}Ga_{0.5}As/GaAs(111)A$ involving thin GaAs buffer layers that behave mechanically similar to compliant substrates.

3:15 PM O5.4
SYMMETRY AND THE NUMBER OF VARIANTS IN EPITAXIAL GROWTH ON LOW-INDEX AND VICINAL SURFACES. Alwyn Eades, Lehigh University, Dept of Materials Science and Engineering, Bethlehem, PA; Peter Flynn, University of Illinois, Department of Physics, Urbana, IL.

If an epilayer is grown on a substrate with three-fold symmetry, the epilayer will grow in three orientations, giving three variants - unless the epilayer also has three-fold symmetry, in which case there is only one variant. This simple idea has been extended to give a complete and accurate result for the number of orientation variants produced for all combinations of substrate symmetry and epilayer symmetry. The rules, from symmetry, governing the way the proportions of the variants are constrained have also been derived. The results are not limited to ideal surfaces but also apply to real surfaces with defects. Results have been obtained for the following cases: substrates having a single terrace; substrates with terraces at different levels (but with an overall orientation parallel to the terraces); and substrates with miscut (vicinal surfaces). These predictions can provide guidance in the selection of the conditions required to grow better films.

3:30 PM O5.5
INFLUENCE OF THE WAFER EDGE ON DEFECT FORMATION IN P/P+ SILICON VAPOR PHASE EPITAXY. Petra Feichtinger, Petra Feichtinger, Jeffrey J. Leininger, Benjamin Poust, Mark S. Goorsky, Dept of Materials Science and Engineering, University of California, Los Angeles, CA; Dwain Oster, Juanita Chambers and Jim Moreland, Wacker Siltronic Corp, Portland, OR.

An essential issue associated with optimizing substrates for devices is the reduction of strain-relaxing defects. A challenge in the fabrication of large diameter epitaxial silicon wafers is the heterogeneous nucleation of misfit dislocations at crystal imperfections around the wafer edges. Our prior investigations in the evolution of misfit dislocations in the low-mismatch p/p+ silicon system showed that different edge treatments of the highly boron doped substrates can help eliminate the misfit segments. We investigated the nucleation process of misfit dislocations in boron doped p/p+ silicon wafers. The samples were 150 mm Czochralski grown wafers with boron concentration $\sim 3 \times 10^{19}$ cm^3. Lightly boron doped (1×10^{15} cm^3), compressively strained epitaxial layers were deposited via vapor phase epitaxy at $\sim$ 1100°C in a single wafer reactor. The strain in the system is about 1.6×10^{-4}. Three different thicknesses beyond the thermodynamically predicted critical one ($\sim 1.2\ \mu$m) were employed. Double axis x-ray diffraction was used to determine the off-orientation of the substrate and the tilt of the epitaxial layer with respect to the substrate due to misfit dislocation density differences. Double crystal x-ray topography and defect etching were used to measure the length, density and properties (Burger's vector and thus glide plane) of the misfit dislocation segments around the wafer periphery. Using high temperature annealing of wafer pieces, the nucleation activation energy for misfit dislocations could be determined in addition to the glide activation energy. Angle lapping, etching and TEM were performed in order to gain insight in the nature of edge roughness acting as misfit dislocation nucleation sites. Electrical measurements were done in regions where the misfit or threading segments existed to quantify the relationship between the defects and device performance. All results suggest that edge treatments have the potential to reduce the formation of strain-relaxing defects in strained epitaxial systems.

3:45 PM *O5.6
BULK TERNARY III-V SINGLE CRYSTAL SEMICONDUCTORS: ON THE ROAD TO SUBSTRATE ENGINEERING. W.A. Bonner, Crystallod Inc., Somerville, NJ.

Single crystal growth of bulk ternary III-V alloys represents a pioneering effort in compound semiconductor substrate technology. It is well known that ternary III-V alloys provide a continuum of physical properties between the binary constituents. Until recently, utility of the ternary III-Vs, could only be realized in the form of epitaxial layers and related devices have been limited to only those properties compatible with close proximity to the binary III-V compounds. Single crystals of ternary III-V alloys permit utilization of the entire lattice parameter, spectral and band-gap regimes from GaP to InSb. Discrete ternary composition alloys will permit realization of the concept of substrate engineering, as well as bulk applications, to address novel device architecture. Contemporary utility, for ternary substrate compositions close to the simple binary III-V substrates, will permit direct lattice matching of epilayers to substrates, thereby avoiding the necessity for costly and often only moderately effective compositionally graded layers.
The ability to grow bulk ternary single crystals approaching minimum commercial size requirements has been demonstrated for $InP_{1-x}As_x$, $Ga_{1-x}In_xAs$, and $Ga_{1-x}In_x$-Sb. Bulk ternary based device structures fabricated attest to material quality and validity of the concept of ternary III-V substrate engineering.

4:15 PM O5.7
GROWTH OF LARGE DIAMETER SILICON-GERMANIUM MONOCRYSTALS. Richard H. Deitch, Stephen H. Jones, Thomas G. Digges, Jr., Virginia Semiconductor, Inc., Fredericksburg, VA.

Si-Ge alloy single crystals up to 50 mm diameter and up to 17 at% germanium were grown using a Czochralski technique. Pre-grown large diameter single-crystal silicon seeds with various crystallographic orientations were used as templates for the alloy solidification to save time and to insure single-crystallinity. Presented are the results and a discussion of the influences of seed preparation, crystal growing and post-growth processing.

4:30 PM O5.8
FORMATION AND STABILITY OF LARGE STEP-FREE AREAS ON Si(001) AND Si(111) SUBSTRATES. Doohan Lee, Jack Blakely, Cornell University, Dept of Materials Science and Engineering, Ithaca, NY.

Controlling the density and distribution of atomic steps on substrate surfaces is important in determining overlayer growth modes and the ultimate electronic properties of heterostructures. We have developed an annealing process to create regular arrays of atomic step-free regions (up to ∼50x50 microns) on Si(111) and Si(001) starting with substrates that are lithographically patterned to have a square grid of ridge structures. The conditions for step-free region formation are different on the two surfaces due to differences in the temperature dependencies of the surface structures and different atomic diffusion characteristics. These atomically engineered substrates are suitable for epitaxial growth. We have also explored the stability of these step-free surfaces against invasion by atomic steps when annealed at extremely high temperature. In a certain temperature range the step-free regions are unstable against the formation of circular vacancy pits due to the build-up of a supersaturation of vacancies at large distances from atomic steps and against the invasion of pre-existing steps from the surrounding barriers. Details of these instabilities will be given for the (100) and (111) surfaces. The influence of electromigration on the arrangement of these extremely widely spaced steps will also be described.

SESSION O6: POSTER SESSION:
SUBSTRATE ENGINEERING
Chairs: David H. Matthiesen, Nate Newman, David P. Norton and Darrell G. Schlom
Wednesday Evening, December 1, 1999
8:00 P.M.
Exhibition Hall D (H)

O6.1
EFFECT OF SEED COLUMN SPACING ON LATERAL GROWTH RATES OF GaN THIN FILMS GROWN VIA PENDEO-EPITAXY. Darren B. Thomson, Eric P. Carlson, Thomas Gehrke, Kevin Linthicum, Pradeep Rajagopal, Mark Edmond, Robert F. Davis, North Carolina State University, Dept of Materials Science and Engineering, Raleigh, NC.

Pendeo-epitaxy (PE) is the selective growth of thin films from the sidewalls of etched forms. This process route is used to grow GaN films from elongated GaN seed columns. The seed columns are etched from GaN grown via metalorganic vapor phase epitaxy (MOVPE) on 6H-SiC(0001) substrates. Scanning electron microscopy (SEM) studies show that lateral PE growth rates are dependent on the flux of reactants to the growth front. The growth rates decrease as the spacing between forms is decreased, while growth on forms with very wide spacing does not exhibit this phenomenon.

O6.2
EFFECTS OF SAPPHIRE SUBSTRATE CONFIGURATIONS ON MBE GROWTH OF ZnO. Keiichiro Sakurai, Shizuo Fujita, Shigeo Fujita, Kyoto Univ, Dept of Elec.Sci. & Eng., Kyoto, JAPAN; Ken Nakahara, Tetsuhiro Tanabe, Rohm Co., Ltd, Kyoto, JAPAN.

Recently, Zinc oxide (ZnO) is being developed for UV semiconductor devices utilizing its remarkable excitonic properties, which may lead to future UV laser devices with the lowest thresholds ever. Despite efforts being made by several groups, quality of ZnO films still needs development for this purpose. One essential factor to be observed is the substrate configuration, particularly of the widely used sapphire c-plane substrates. In this work, we have made a close investigation on the effects of sapphire substrate configurations, using MBE method with metallic Zn and RF oxygen plasma as source materials. Offset angle from *c*-plane sapphire were found to largely effect the ZnO film quality, mainly its structural properties. Current results show that the best results are to be obtained with offset angles between 0.05 - 4 degrees, being involved with the conditions of oxygen plasma. Effects combined with substrate manufacturer and post-cutting processes were observed. Comparison with the case of bulk ZnO substrates were also made. Quality of the ZnO films were observed by PL, XRD, RHEED, SEM and Hall measurements. Finally, we will discuss the effects of substrate conditions on p-type doping of ZnO.

O6.3
MOLECULAR BEAM EPITAXIAL GROWTH AND CHARACTERIZATION OF TiO_2 ANATASE THIN FILMS. Yong Liang, Shupan Gan, Thuy Tran and Scott Chambers, Pacific Northwest National Laboratory, Richland, WA.

Although the anatase phase of TiO_2 is an important dielectric and photocatalytic material, investigations of the physical and chemical properties of anatase have been very limited due primarily to the difficulty in preparing large anatase single crystals. We have successfully grown single-crystal epitaxial anatase thin films on $SrTiO_3$(001) substrates using oxygen plasma assisted molecular beam epitaxy (MBE). The resulting films and surfaces have been characterized using several techniques such as reflection high-energy electron diffraction (RHEED), x-ray photoelectron spectroscopy (XPS), scanning tunneling microscopy (STM), and x-ray diffraction (XRD). Results show that well-ordered, single-crystal anatase films form at substrate temperatures between 450 to 600°C with growth direction along c-axis. In contrast to most of other oxide thin film growths, XRD reveals a decrease in the crystallinity of the anatase films with increasing growth temperatures, indicating the competition between anatase and rutile phase yields larger defect density at higher growth temperatures. RHEED and STM show that the films grown at 450 to 500°C are more laminar but island growth predominates at 520 to 600°C. The roughness of the laminar films is less than 3 Å. The surface of MBE-grown anatase exhibits an unreconstructed 1x1 structure and appears to be fully oxidized, with no evidence of formation of Ti^{3+}.

O6.4
FACETING OF THE (100) FACE OF SINGLE-CRYSTAL STRONTIUM TITANATE DURING WET CHEMICAL ETCHING. G.C. Spalding, W.L. Murphy, T.M. Davidsmeier, J.E. Elenewski, Illinois Wesleyan Univ, Dept of Physics, Bloomington, IL.

We use an Atomic Force Microscope (AFM) to study the evolution of single crystal $SrTiO_3$ surfaces etched in HF-based solutions. Our attention in this poster is focused upon observations of pyramidal pitting. For a variety of etch conditions, we measure etch rates, along with the temporal evolution of the etch pits. Within this context, we discuss general strategies for $SrTiO_3$ surface preparation.

O6.5
TiN(111) : A POTENTIAL BUFFER LAYER FOR EPITAXIAL GROWTH OF GaN ON Si(111). S. Kang, University of Tennessee, Dept of Physics and Astronomy, Knoxville, TN; C.M. Rouleau, J.D. Budai, D.H. Lowndes, Oak Ridge National Laboratory, Solid State Div, Oak Ridge, TN.

Thin films of TiN were deposited on 4° miscut Si(111) substrates by pulsed KrF-laser ablation of a hot-pressed TiN target (99.5% purity) through vacuum (nominally 10^{-7} torr) at deposition temperatures ranging from 500 to 1050°C. The target was positioned 5 cm from the substrate and ablated using a reimaging beamline (i.e., single spherical lens imaging an aperture onto the target at demagnification) at a nominal energy density, $E_d = 3$ J/cm^2. To avoid the difficulty in guaranteeing E_d from run-to-run, the chamber was equipped with an ion probe which was used to first determine the TiN ablation threshold energy and then the time-of-flight (TOF) at 1.25X the threshold energy. The TOF was measured to be 3.19μs and was used routinely instead of E_d. To inspect the substrate cleaning process after setting the TOF and prior to film-growth as well as the quality of the subsequent TiN layers, the chamber was equipped with RHEED. X-ray diffraction (XRD) revealed highly textured films in all cases and the texture was improved with increasing temperature. The best film, grown at 1050°C, had a rocking curve width of 0.3° around TiN(111) and a mosaic spread of 0.43° around TiN(002). The film consisted of two domains separated by 60° despite the substrate miscut and the TiN(111) and Si(111) planes were parallel ($\leq$ 0.01° separation) with no tilt toward the surface normal. The film was under in-plane compression with a tetragonal distortion of 1.0057. In-situ RHEED patterns of the films were streaky and qualitatively mirrored the XRD trends. Subsequent deposition of GaN by pulsed laser ablation of molten Ga through activated ammonia was performed. In this paper we will discuss these results. This research was carried out at Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corp. for the U.S. Dept. of Energy under contract DE-AC05-96OR22464.

O6.6
AlN/SAPPHIRE SUBSTRATE ENGINEERING VIA SPER FOR GaN EPITAXY. R. Enck, R.D. Vispute, S. Choopun, S.B. Ogale, R.P. Sharma and T. Venkatesan,CSR, Department of Physics, University of Maryland, College Park, MD; T. Zheleva and K. A. Jones, U.S. Army Research Laboratory, Adelphi, MD.

High quality and lattice matched buffer layers are needed for the growth of device quality GaN thin films on sapphire. In this context, we report on the fabrication of high quality AlN thin films through a novel process called solid phase epitaxial regrowth (SPER). In this process, as grown amorphous and crystalline AlN thin films having a large defect concentration (such as threading dislocations due to a large lattice mismatch between AlN and sapphire and low angle grain boundaries) were thermally annealed in an inert atmosphere at various temperatures ranging from 1200-1600C for 0.5 to 3.0 hrs. The as-grown and annealed samples were characterized by x-ray diffraction, transmission electron microscopy (TEM), Rutherford backscattering spectroscopy (RBS), atomic force microscopy (AFM) and UV-visible spectroscopy. Ion channeling/RBS and TEM results clearly indicate a substantial reduction in defect density for the recrystallized AlN films. The surface morphology of the SPER AlN films was smooth with a surface roughness close to the unit cell height. The optical bandgap was sharp as compared to as grown films, with a bandgap of 6.2 eV. Similar studies were carried out for the $Al_xGa_{1-x}N$ (x= 0.5 to 1) films. These regrown films were used as high quality buffer layers for the growth of GaN films. The issues related to the SPER, regrowth mechanism, defect removal process, effect of film thickness, and properties of the subsequent growth of GaN thin films will be discussed.

O6.7
HIGH TEMPERATURE VAPOR PHASE ETCHING OF GROUND SILICON SUBSTRATE FOR EPITAXY. Yifei He, Gregory Zakaluk, General Semiconductor, Inc., Westbury, NY.

We have been using the low-cost method of fabrication of epitaxial wafer for discrete devices for many years. This low-cost operation is done by eliminate the conventional but costly polishing procedure, instead of grinding, cleaning and etching processes prior to epitaxial growth. The etching step is needed to remove any residual grinding scratches and possible remaining contamination. It is accomplished with HCl gas at a temperature range from 1120 to 1150°C, at atmospheric pressure, and over a range of HCl and H_2 flows. In this study, the surface analysis and inspection techniques were used to test residual grinding scratch removal, etch rate and its uniformity due to the chemical concentration and temperature. The temperature dependence of the etch rate is found to be small, but the surface morphology with ground pattern is very sensitive to the etching temperature. The study revealed the presence of regions of temperature and HCl concentration in which the silicon surface is with minimum grinding scratches and little etch pits. A kinetic model involving formation of an HCl complex on the substrate surface has been formulated which explains the results quantitatively. This theory suggests that the effects on removal of scratches are primarily causes by the surface kinetics and the thermodynamic equilibrium of the chemical reactions.

O6.8
THEORETICAL STUDY ON THE POTENTIAL ENERGY SURFACE OF METAL-SOLID SURFACE INTERACTION AS INVESTIGATED BY PERIODIC DENSITY FUNCTIONAL CALCULATIONS. Akira Endou, Kentaro Yoshizawa, Yusaku Inaba, Nobumoto Ohashi, Seiichi Takami, Momoji Kubo, Akira Miyamoto, Graduate School of Eng., Tohoku Univ., Sendai, JAPAN; Ewa Broclawik, Polish Academy of Sciences, Cracow, POLAND.

A great deal of effort has been made on the improvement of various functional materials. However, more detailed informations at atomic and electronic scale, such as understanding the surface structures of the substrate and the interaction at the heterointerface are required. In this study, we have carried out the periodic density functional (DF) calculations to elucidate the potential energy surface (PES) for Pd/MgO(001) system. The calculated interaction energy revealed that the interaction of the Pd atom with the oxygen atom of MgO(001) surface was relatively preferable and this is in well accordance with the *ab initio* results reported earlier [1]. We also attempted to fit these periodic DF results to Morse-type 2-body, central force interatomic potential. Fitted Morse-type functions which represent the Pd-O and Pd-Mg interactions can substantially reproduce the results obtained from periodic DF calculations. Next, the PES was derived to discuss the possibility of the migration of Pd atom supported on the MgO(001) surface. From the PES, a plausible path for the migration of the supported Pd atom is proposed. The Pd adatom migrates over the hollow site to the next O site and this process has the activation barrier of about 8.33 kcal/mol. Such proposed path is qualitatively in agreement with the other theoretical studies [2]. In order to validate the above findings, the classical molecular dynamics simulations were also carried out starting from various initial positions of supported Pd atom.
[1] I. Yudanov, G. Pacchioni, K. Neyman, N. Rösch, J. Phys. Chem. B **101**, 2786 (1997).
[2] Y. Li, D.C. Langreth, M.R. Pederson, Phys. Rev. B **52**, 6067(1995).; V. Musolino, A. Selloni, R. Car, J. Chem. Phys. **108**, 5044(1998).

O6.9
SELECTIVE AREA GROWTH OF MAGNETIC GARNET CRYSTALS BY LIQUID-PHASE EPITAXY. Hideki Yokoi, Tetsuya Mizumoto, Tokyo Institute of Technology, Dept of Physical Electronics, Tokyo, JAPAN.

Magnetic garnet crystals are necessary to construct optical nonreciprocal devices such as optical isolators and circulators. Selective area growth of the magnetic garnet layers was studied by means of liquid-phase epitaxy. The magnetic garnet layers of composition $(LuNdBi)_3(FeAI)_5O_{12}$ (LNB) were grown on (111)-oriented $Gd_3Ga_5O_{12}$ (GGG) substrates, partially covered by Ti mask, by liquid-phase epitaxy. The garnet layers were investigated by scanning electron microscope, X-ray diffraction measurement, energy dispersive X-ray analysis and reflection high-energy electron diffraction. The analyses indicated that single crystals were epitaxially grown on the mask-free region, while polycrystalline coverage was observed on the masked region. The layers grown on the Ti masked region had a coarse and uneven surface, which is attributed to a damaged surface of GGG substrates during the growth. The composition of the layers grown on the Ti masked region was almost same as that of the magnetic garnet grown on the mask-free region. The LNB layers were grown on the GGG substrates, patterned with stripes of different width using the Ti mask, to fabricate one-step grown magnetic garnet waveguides. The cross-sectional SEM images indicated that trapezoidal and triangular waveguides were fabricated in wide and narrow stripes, respectively. The side wall had a specific crystal facet so that low optical propagation loss of the waveguide is expected. This technique is applicable to fabricate optical nonreciprocal devices of a waveguide type.

O6.10
EPITAXIAL REALIGNMENT OF IN-SITU DOPED POLYCRYSTALLINE SILICON FOR ADVANCED BiCMOS

TECHNOLOGIES. Kevin Chang, Tan-Chen Lee, Richard Gregory, Kari Noehring, Jim Kirchgessner, Gilles Fresquet, John Parker, Motorola Inc., Mesa, AZ; Bernd Tillack, Institut Fur Halbleiterphysik, Frankfurt (Oder), GERMANY.

Feasibility of an in-situ-doped (ISD) polycrystalline Si process using chemical vapor deposition for advanced BiCMOS technologies is presented. ISD As-doped amorphous and polycrystalline Si layers have been deposited on Si substrates at 610 deg.C and 660 deg.C, respectively, with a deposition rate of about 12.5 nm/minute. Samples are compared on the basis of having been subjected to substrate preclean prior to deposition using HF solution and in-situ H2 bake. TEM micrographs reveal the presence of thin (1-1.5 nm) oxide at the interface of the deposited Si and substrate for samples not precleaned. This is confirmed for both the amorphous and polycrystalline Si depositions. However, for 610 deg.C-deposited samples given the substrate preclean, a polycrystalline structure with partial epitaxial layer growth is observed. Twins and stacking faults are found at the poly Si/single crystal Si interface, causing interfacial roughness. Post-deposition annealing of Si films typically generates grain growth, but RBS-channeling characterization of the annealed Si provides evidence of some recrystallization, the extent of which is affected by the original growth condition. The analysis shows that the amorphous deposition at 610 deg.C actually results with a mixture of epitaxial and polycrystalline Si. Following a 1040 deg.C anneal, approximately 50 nm at the interface region of the 190 nm polycrystalline Si film has become an epitaxially realigned Si layer with a measurably rough interface to the substrate. Layers grown at higher temperature (660 deg.C) reach approximately 230 nm in thickness, but the extent of recrystallization following anneal measures less, suggesting the presence of larger poly grains that retard transformation to single crystal Si. The experiment suggests that Si atoms tend to align to a clean Si substrate, even at low temperature, generating early-stage epitaxial growth that eventually breaks down due to formation of micro twins and stacking faults. Epitaxial realignment of the polycrystalline Si film by post deposition annealing can result with significantly improved device performance.

O6.11
THE EFFECT OF STRESS IN THE PdGe MEDIATED SOLID PHASE EPITAXIAL GROWTH OF Ge ON GaAs. F. Radulescu, J.M. McCarthy, Oregon Graduate Institute of Science and Technology, Dept of Materials Science and Engineering, Portland, OR.

The residual stress and the microstructure associated with it were studied in connection with the Pd-Ge ohmic contact formation on GaAs. Evaporated Pd (20 nm) / Ge (150 nm) / Pd (50 nm) thin film stacks on GaAs were annealed at various temperatures and the resulting microstructures were investigated by transmission electron microscopy (TEM). Micro-cantilever beam structures were fabricated with a focused ion beam (FIB) workstation and the residual stress present was calculated from the deflection magnitude. It was found that Ge solid phase epitaxial (SPE) growth on GaAs is associated with a stress relaxation of the thin film system. A new model that suggests the tensile stress induced by the intermediate layer may play an important role in the SPE growth mechanism is proposed. Other cases of solid phase heteroepitaxial growth with an intermediate medium, such as Ge/Au/Si, Co/Ti/Si (the TIME method) and Co/SiO_x/Si (the OME method) are discussed in light of this newly proposed model. Also, the possibility of using controlled stress to engineer new methods for growing SPE based heterostructures will be presented.

O6.12
INVESTIGATION ON HETEROEPITAXIAL GROWTH OF GaN FILM ON SAPPHIRE BY COMPUTATIONAL CHEMISTRY. Takayuki Onozu, Yusaku Inaba, Seiichi Takami, Momoji Kubo, Akira Miyamoto, Tohoku Univ., Dept. of Materials Chemistry, Sendai, JAPAN; Yasushi Iyechika, Takayoshi Maeda, Sumitomo Chemical Co. Ltd., Tsukuba Research Lab., Tsukuba, JAPAN.

Gallium nitride is one of the most attractive materials for optoelectronic devices because of its application in blue light-emitting diodes and lasers [1]. These GaN device structures were grown mainly on sapphire, although their lattice parameters and thermal expansion coefficients differ greatly from those of GaN or related mixed alloys. In recent years, the heteroepitaxial growth of highly perfect GaN layers on sapphire substrates by the metalorganic vapor phase epitaxy method has become possible due to the development of the GaN or AlN buffer layer deposition technique [2]. However, as for the initial growth process of the GaN films, the microstructure of GaN/sapphire interface and the growth mechanism are not well known yet. In the present study, we have investigated the microstructures and the electronic states of the GaN/sapphire (0001) heteroepitaxial interface by the molecular dynamics (MD) and the periodic density functional theory (DFT) methods. We performed the MD simulations of the initial heteroepitaxial growth process of GaN thin films on sapphire (0001) substrate at 1200 K. The GaN molecules were deposited at regular time intervals and diffused over the sapphire surface. Since the N atoms of GaN interacted strongly with the Al atoms from sapphire, the degree of surface diffusion of N atoms is not so large. Furthermore, it was observed that the Ga atoms tended to assemble around the step edge of sapphire surface. We calculated the energetically stable sites of GaN on the sapphire (0001) surface by the DFT calculations and suggested that the Al-N bond is the most stable on that surface.
[1] S. Nakamura, M. Senoh, S. Nagahama, N. Iwasa, T. Yamada, T. Matsushita, H. Kiyoku, and Y. Sugimoto, Jpn. J. Appl. Phys. 35 (1996) L74.
[2] S. Nakamura, Jpn. J. Appl. Phys. 30 (1991) L1705.

O6.13
RECENT PROGRESSES OF OPTOELECTRONIC DEVICES GROWN ON COMPLIANT SUBSTRATES. W.-Y. Hwang, C. H. Kuo*, Chih-Hsiang Lin*, A. Delaney* and S.J. Murray*, Applied Optoelectronics Inc., Sugar Land, TX; *also with SVEC, University of Houston, Houston, TX.

In the past few years, universal compliant substrates are attracting more and more applications for both electronic and optoelectronic devices. A compliant substrate, which can be used to grow high quality III-V thin films with various lattice constants, will have a huge impact on the semiconductor field. Many device structures that were previously limited by the available lattice constants of commercial substrates can now be grown on the compliant substrates, such as InAs channel HEMT, far-IR Sb-based detectors, 1.3 μm and 2.5 μm InGaAs quantum well (QW) lasers. It is also advantageous for some applications that a semi-insulating compliant substrate can be used to replace existing substrates that do not have available semi-insulating ones, such as GaSb. Recently, there are some encouraging reports on devices grown directly on compliant substrates. New applications are exploited utilizing this compliant substrate technology. Nevertheless, more research effort is needed to develop the new applications on this technology. Here we will report our recent research results on some of the optoelectronic devices, including lasers and infrared photodetectors, grown on InGaAs/GaAs compliant substrates by solid source MBE.
We have demonstrated high-power 4-μm Mid-IR type-II InAs/InGaSb QW lasers grown directly on InGaAs/GaAs compliant substrates. The lattice mismatch between the type-II QWs and GaAs substrate is as high as 8.5%. The device is pumped by a 980-nm pump source with 10-μsec pulses and 1% duty cycle. A peak power larger than 320 mW per facet and an external differential quantum efficiency (DQE) of 7.2% was achieved. This DQE is similar to the one grown on GaSb substrate. Under high-power pumping conditions for several days, these lasers showed no observable degradations in the device performances. We have also studied the type-II superlattice InAs/InGaSb QW detectors grown on a compliant GaAs substrate by molecular beam epitaxy. This superlattice was designed for photoconductive infrared detection in the long wavelength infrared band. The spectral photoresponse of this superlattice shows a sharp onset at 76.9 meV and a corresponding cut-off wavelength at 13.9 μm. A six-fold increase in the peak photoresponse was measured in comparison to the response from a similar superlattice on a standard GaSb substrate. All of these promising results demonstrate the feasibility of compliant substrates. Further researches will be performed on the studies of devices grown on these new substrates. We will report more recent results on the development of these devices and other new devices, such as 1.3 μm VCSEL and IR photodiodes, grown on compliant substrates.

O6.14
HELIUM IMPLANTATION FOR STRAIN RELAXATION OF EPITAXIAL LAYERS ON III-V SUBSTRATES. Martin Chicoine, Sjoerd Roorda, Université de Montréal and Thin Layers Research Group (GCM), Montréal, CANADA; Remo A. Masut, École Polytechnique de Montréal and GCM, Montréal, CANADA.

Recently, Mantl and al. [1] have shown that strain in epitaxial SiGe grown on Si substrates could be relaxed by hydrogen implantation and thermal annealing. Hydrogen is implanted slightly below the SiGe/Si interface forming platelets and cavities during subsequent annealing. Samples treated this way showed strongly enhanced strain relaxation in the SiGe epilayers attributed to preferred nucleation of dislocation loops in the hydrogen implanted layer. We study the possibility of using a similar method to accommodate strain in epilayers grown on III-V substrates and to avoid the formation of threading dislocations when growing layers exceeding the critical thickness. We have found the conditions under which helium implantation and subsequent annealing form cavities in various III-V substrate materials; we are now evaluating MOCVD growth on such substrates. We will present results on heterostructures involving InAsP on InP substrates, relevant for optical modulators and other integrated optics applications, which often require thick active regions, and for which the large compressive strains in the InAsP might rapidly lead to plastic relaxation. [1] S. Mantl, B. Hollander, R.

Liedtke, S. Mesters, H.J. Herzog, H. Kibbel and T. Hackbarth, Nucl. Instr. And Meth. B 147 (1999) 29.

O6.15
COMBINED EFFECTS OF BUFFER LAYER THICKNESS AND COMPOSITIONAL GRADING IN InAs/InGaAs/GaAs(111) A HETEROEPITAXY. R.I. Pelzel, L.A. Zepeda-Ruiz, B.Z. Nosho, W.H. Weinberg, and D. Maroudas, Department of Chemical Engineering and Center for Quantized Electronic Structures (QUEST), University of California, Santa Barbara, CA.

Recent experimental and theoretical work has demonstrated that the mechanical behavior of the InAs/GaAs(111)A heteroepitaxial system depends on the thickness of the GaAs buffer layer grown on the epi-ready substrate. We have investigated this dependence in the presence of compositionally graded layers based on an experimental study of InAs/$In_{0.5}Ga_{0.5}As$/GaAs(111)A heteroepitaxy. In our experiments, the $In_{0.5}Ga_{0.5}As$ thickness was set at one monolayer (ML) and two GaAs buffer layer thicknesses were studied: 10 ML and 0.15 μm. Strain relaxation as a function of InAs coverage has been determined by changes in the in-plane lattice constant, as measured by reflection high-energy electron diffraction, and the surface morphology of the InAs films as a function of InAs coverage has been imaged by scanning tunneling microscopy (STM). Strain relaxation for growth on the 10 ML GaAs buffer occurs more gradually than growth on the 0.15 μm buffer. Furthermore, the effect of the $In_{0.5}Ga_{0.5}As$ graded layer is the decrease of strain relaxation at a given InAs coverage and GaAs buffer layer thickness as compared to the corresponding InAs/GaAs(111)A data. STM data demonstrate and quantify the dependence of the InAs film surface morphology on the GaAs buffer layer thickness. Specifically, the vertical surface displacements in the InAs film that result from the underlying misfit dislocation network are consistently lower for the 10 ML buffer layer as compared to the 0.15 μm buffer layer. Comparing the magnitude of the film's vertical surface displacement for the InAs/$In_{0.5}Ga_{0.5}As$/GaAs(111)A system to that of the InAs/GaAs(111)A system also suggests that the graded layer results in more gradual strain relaxation. These results reinforce the concept that thin GaAs buffer layers act mechanically similar to compliant substrates. Moreover, this effect can be coupled with compositional grading for further engineering of mechanical behavior. Our experimental results are compared with theoretical calculations. Additional experimental evidence for mechanical behavior of the thin buffer layers also will be discussed.

O6.16
SELECTIVE EPITAXY OF CADMIUM TELLURIDE ON SILICON BY MBE. R Sporken, F. Wiam, Facultés Universitaires Notre-Dame de la Paix, Namur, BELGIUM; G. Brill, P. Boieriu, D. Grajewsiki, A. Prociuk, Y. Xin, S. Rujirawat and S.Sivananthan, University of Illinois at Chicago, Microphysics Laboratory, Chicago, IL.

There is a general interest in heteroepitaxy with small lateral dimensions for monolithic integration applications. We report on a study of selective growth of CdTe on Si(111) by MBE. Nucleation of CdTe on Si(111) during MBE was studied by RHEED. First, a monolayer of As was deposited, as it is known that this favors growth of CdTe(111)B (Ref.1). The highest temperature where CdTe nucleates on such Si surfaces is typically in the range of 220 - 250C. On a SiO_2 mask , CdTe nucleates at the same temperatures, leading to polycrystalline growth. Hence, SiO_2 is not suitable as a mask to achieve selective growth. Selective growth was achieved by exploiting the fact that homoepitaxy of CdTe is possible around 300C, which is at least 50C higher than the temperature required to nucleate CdTe on Si(111). First, a thin seed layer of CdTe was grown using our regular CdTe/Si(111) growth procedure. Two sets of CdTe stripes, parallel to [011] and [211], were defined by optical lithography, leaving areas of bare Si(111) between the stripes. CdTe was then grown by MBE on such patterned substrates, at a substrate temperature near 300C. This results in growth on the stripes, and no growth between the stripes which is very promising. References 1. S. Rujirawat, Y. Xin, N.D. Browning, S. Sivananthan, D.J. Smith, S.-C.Y. Tsen, Y.P. Chen, V. Nathan, Appl. Phys. Lett. 74, 2346 (1999).

O6.17
MECHANICAL EXFOLIATION OF ION-IMPLANTED Si LAYERS. K. Henttinen, I. Suni, Microelectroanics Centre, VTT Electronics, Espoo, FINLAND; and S.S. Lau, Department of Electrical and Computer Engineering, University of California-San Diego, La Jolla, CA.

We demonstrate in this work the mechanical exfoliation of H-implanted Si to form SOI structures. The critical issue to achieve this process is to improve the bonding strength of the bonded pair to exceed the fracture strength of the bulk Si. Delamination occurs in the H-implanted layer since it is the weakest region of the bonded pair due to implanted H-Si interactions.

O6.18
WET ETCHING METHODS FOR PEROVSKITE SUBSTRATES. Victor Leca, Gertjan Koster, Guus J.H.M. Rijnders, Dave H.A. Blank and Horst Rogalla, Univ. of Twente, Applied Physics Dept., Enschede, THE NETHERLANDS.

In oxide electronics substrates with atomically flat terraces are a request for growing high-quality epitaxial thin films. Among them, $SrTiO_3$, a dielectric material with a perovskite structure, is often used. In order to obtain high quality $SrTiO_3$ substrates, different etchants (NH_4F - HF, NH_4Cl - HCl, HCl, and aqua regia) with various pH values have been studied. The $SrTiO_3$ (001) substrates were soaked in pure water for 20 - 30 min, immersed in the etchant for different periods of time, rinsed with pure water for 20 min, and finally dried in nitrogen stream. The entire procedure takes place in an ultrasound bath, at temperatures between 20 and 70 degree Celsius. The etched samples are annealed at 950 - 1000 degree Celcius, in oxygen. From Atomic Force Microscopy (in air) we conclude that, irrespective of the etchant that has been used, a $SrTiO_3$ surface with a TiO_2 terminated layer and atomically flat terraces without etch pits could be obtained. The pH-value and temperature of the etchant and the etching time, however, influences the surface quality significantly. Reflected high energy diffraction patterns confirmed the AFM results. The same procedure has been applied to different other perovskite substrates. In this contribution an overview will be given about the latest results.

O6.19
STRAIN RELAXATION MECHANISM IN LATTICE ENGINEERED SUBSTRATES. S.K. Mathis, P. Chavarkar, U.K. Mishra, and J.S. Speck, Materials and Electrical Engineering Departments, University of California, Santa Barbara, CA.

Lateral oxidation of AlAs has been used to relax strained InGaAs overlayers grown on GaAs substrates. InGaAs layers were grown beyond the critical thickness for dislocation formation (h_c) at low growth temperatures (i.e., 350°C). As-grown, the InGaAs layers were partially strained (40% of the strain is relaxed for $In_{.2}Ga_{.8}As$ layers at $20{\cdot}h_c$). After oxidation, the layers are as much as 90% strain relaxed. These lattice engineered substrate (LES) templates were used as substrates for further regrowth. In contrast to compliant substrates, this method relies on partially relaxed layers which are then further relaxed without the creation of more defects. The focus of the current work is to understand the mechanism of strain relaxation in these layers. As-grown and oxidized template structures were observed via plan-view transmission electron microscopy (PVTEM). An $In_{.2}Ga_{.8}As$/AlAs/GaAs structure was patterned and etched to reveal the AlAs sidewalls and the 100x100 μm mesas were oxidized at 450°C. The misfit dislocation (MD) density in the plane of the interface between InGaAs and the underlying AlAs layer decreased from 1.67×10^5/cm before oxidation to 5.91×10^3/cm after oxidation. The amount of relaxed misfit strain increased from 40 to 90%. The threading dislocation (TD) density remained constant as measured via PVTEM and by etch pit density measurements at $\sim10^6/cm^2$. The MD density decreased by the removal of a crystalline interface between the AlAs and the InGaAs. This allows the MDs to glide out of the film at the bottom interface between the amorphous or nanocrystalline AlOx and the InGaAs layer. At the same time, a deformation wave passes through the material at the oxidation front, while the AlO_x may also be experiencing extensive mass transport. This allows the InGaAs layer to relax as oxidation proceeds. Regrown material on these LESs is also relaxed. However, PVTEM of these regrown films has consistently shown a high TD density. TD densities of $\sim5\times10^8/cm^2$ have been measured in both InGaAs and GaAsSb regrowths. Since the TD density increases upon regrowth at lattice-matched conditions, *in-situ* surface preparation for regrowth is the probable cause of poor film quality. This is done by Ar+ ion sputtering of the native oxide, which may result in only partial oxide removal and surface roughening.

SESSION O7: LATTICE MISMATCH ENGINEERING II
Chair: Nate Newman
Thursday Morning, December 2, 1999
Harvard (M)

8:30 AM *O7.1
GROWTH OF GaN ON H6-SiC(0001) STUDIED BY LOW-ENERGY ELECTRON MICROSCOPY, ATOMIC FORCE MICROSCOPY AND TRANSMISSION ELECTRON MICROSCOPY. A. Pavlovska, C.W. Hu, V.M. Torres, E. Bauer, D.J. Smith, R.B. Doak, and I.S.T. Tsong, Department of Physics and Astronomy, Arizona State University, Tempe, AZ.

The heteroepitaxial growth of GaN(0001) layers on 6H-SiC(0001) substrates was studied *in situ* and in real time using the low-energy electron microscope (LEEM), and *ex situ* using the atomic force microscope (AFM) and transmission electron microscope (TEM). The Ga flux was supplied by an evaporative cell while the gas flux consisted of NH_3 molecules seeded in a He supersonic beam. The growth was conducted with different flux ratios at a temperature range of 600 - 700°C. Two-dimensional basal plane growth was generally observed under Ga-rich growth conditions, sometimes in the presence of Ga liquid droplets on the film surface.
This work was supported by ONR and NSF-MRSEC.

9:00 AM O7.2
AlN-BASED OVERLAYERS FOR III-N SUBSTRATES. Z.Y. Fan, G. Rong, N. Newman, Dept of Electrical and Computer Engineering, Northwestern University, Evanston, IL; D.J. Smith, D. Chandrasekhar, Center for Solid State Science, Arizona State University, Tempe, AZ.

AlN overlayers have been synthesized using ultra-high substrate temperatures (1000-1450 C) and monoenergetic activated-nitrogen beams (1-40 eV kinetic energies) for the development of novel III-N substrates. AlN films on 6H-SiC with smooth surfaces ($\sim$15 Å rms) and X-ray diffraction (0002) rocking curve widths less than 2 arc min. are routinely achieved using moderate substrate temperature ($\sim$1100 C) and high kinetic energy-activated nitrogen species (>30 eV). The mosaic nature of columnar growth can be decreased by using even higher substrate temperatures (>1150 C), however the reduced sticking coefficients (<0.05) limit the use of these conditions to initial buffer layer nucleation. Additionally, post-growth anneals at elevated temperature (e.g. >1350 C) improve buffer layer quality, without significant decomposition (<200 Å/hour). These results indicate that optimized material can therefore be produced using the extreme condition of 30+ eV reactant beam, 1150+ C substrate temperatures and 1350+ C post-growth anneals to make the buffer layer, followed by moderate substrate temperatures for the deposition of the thicker overlayer. Detailed microstructural characterization by Transmission Electron Microscopy, combined with X-ray diffraction analysis of symmetric and asymmetric Bragg peaks, are used to access structural quality and determine dislocation densities. A detailed investigation of the growth chemistry, including measurements of the forward and reverse reaction rates, sticking coefficients, and incorporation/decomposition rates as a function of the growth conditions will be reported and compared to the resulting AlN structural properties. Supported by the Office of Naval Research (contract No. N00014-96-1-1002).

9:15 AM O7.3
THE USE OF AlN INTERLAYERS TO IMPROVE GaN GROWTH ON A-PLANE SAPPHIRE. D.D. Koleske, M.E. Twigg, A.E. Wickenden, R.L. Henry, R.J. Gorman, J.A. Freitas, Jr., M. Fatemi, Naval Research Laboratory, Washington, DC.

The lack of a suitable, lattice matched substrate for the growth of the group III nitrides typically restricts GaN film growth to substrates such as sapphire or SiC, despite the large lattice and thermal mismatch. With the use of AlN or GaN nucleation layers (NL), GaN films of sufficient quality have been produced for blue LEDs. However, for laser and large-area microwave device applications, the large number of dislocations ($> 10^8$ cm^{-2}) limit device performance, and techniques are highly desired to reduce dislocation density during the growth process. In this presentation, we demonstrate how low temperature AlN interlayers (IL) [1] sandwiched between high temperature (HT) GaN layers can be used to improve the electrical, optical, and structural properties of Si doped GaN films. For a 2 μm Si doped GaN film grown on top of a 5 layer AlN IL/HT GaN layer structure, a room temperature electron mobility of 725 cm^{2}V^{-1}s^{-1} was measured for n = 1.5x10^{17} cm^{-3}. This represents a nearly two-fold increase in mobility compared to a Si doped GaN film grown on a single AlN NL. Cross-sectional transmission electron microscopy images reveal a significant reduction in the screw dislocation density for GaN films grown on multiple AlN IL. Photoluminescence spectra of undoped and Si doped GaN films on the multiple AlN IL/HT GaN layers have small yellow band intensity. An analysis of the electrical data based on a single donor/single acceptor model suggests that the improved electron mobility is the result of a reduced acceptor concentration in the top GaN film. The reduction in the calculated acceptor concentration may be associated with the reduction of in screw dislocation density. Sponsored by the Office of Naval Research.
[1] H. Amano, et al., MRS J. Nitride Semicond. Res. 4S1, G10.1 (1999).

9:30 AM O7.4
SOLID PHASE EPITAXIAL REGROWTH OF AlN FILMS ON SAPPHIRE: A NOVEL SUBSTRATE APPROACH FOR GaN. R.D. Vispute, R. Enck, S. Choopun, S.B. Ogale, R.P. Sharma, and T. Venkatesan, CSR, Department of Physics, University of Maryland, College Park, MD; T. Zheleva and K.A. Jones, U.S. Army Research Laboratory, Adelphi, MD.

The success of utilizing the full potential of III-nitrides has not been fully realized due to the lack of high-quality, lattice-matched substrates. Despite its poor structural and thermal match to GaN, sapphire has been the substrate of choice due to its low cost, availability in a large-area wafers, and its high optical transparency in the UV-visible region. However, as-grown nitride films on sapphire are known to contain a high density of defects (mainly threading dislocations due to a large lattice mismatch of 16%), which affect the optoelectronic properties and life time of the devices. In this paper, we reporton the formation of high quality single crystal AlN films on sapphire (0001) via solid phase epitaxial regrowth (SPER) of pulsed laser deposited AlN films. As-grown AlN films containing various concentrations of defects were thermally treated for SPER in the temperature range of 1200C to 1600C for 30 minutes in an inert atmosphere. Substantial improvements in the structural and the surface qualities have been observed for the films annealed in the range of 1400-1500C. Tilting in the recrystallized layers has been reduced by a factor of ten, while dislocation densities have been reduced more than two orders of magnitude. In addition, the surface of the annealed films was found to be smooth up to annealing temperatures of 1500C. This indicates that the SPER conditions are ideal for the migration of low angle grain boundaries, threading dislocations, and formation of defect free AlN films on sapphire. The films are relaxed and show formation of an interfacial layer. The mechanism of lattice and thermal strain relaxation, role of impurities in the solid phase epitaxial regrowth, compliancy of sapphire substrate, and application of the SPER of AlN along with low lattice mismatch AlGaN layers for the growth of GaN will be discussed.

9:45 AM O7.5
INVESTIGATION OF HETEROSTRUCTURE BETWEEN α-Al_2O_3 AND NITRIDE SEMICONDUCTOR. Yusaku Inaba, Takayuki Onozu, Ryuji Miura, Seiichi Takami, Momoji Kubo, Akira Miyamoto, Tohoku Univ, Dept of Materials Chemistry, Sendai, JAPAN.

The α-Al_2O_3 is the most commonly used substrate for epitaxial growth process of multilayer structures. Since, the quality of epitaxial layers strongly depends on surface morphology. It is important to control the interface between substrate and epitaxial layers. In this study, we investigated the effect of Al_2O_3(0001) surface on AlN and GaN growth process using the computational chemistry methods. We performed the Molecular Dynamics calculations of the AlN and GaN deposition process on Al_2O_3(0001) surface at different temperatures (300, 600, 900 and 1200K). It is found that in the case of deposition of trimer the stable structure of the AlN molecules aggregates at all temperatures, because the interactiobn between AlN molecules is more strongly than between AlN molecule and Al_2O_3 surface. On the other hand, GaN can form the epitaxial layer at low temperature since the interaction between GaN and Al_2O_3 surface is stronger than interaction between the GaN molecules. This result is also supported by our DFT calculations.

10:30 AM O7.6
STRAIN RELAXED $Si_{1-x}Ge_x$ LAYERS ON Si(100) AFTER HYDROGEN IMPLANTATION. B. Hollander, S. Rongen, St. Mesters, S. Mantl, ISI, Forschungszentrum Jülich, Jülich, GERMANY; H. Trinkaus, IFF, Forschungszentrum Jülich, Jülich, GERMANY; H.-J. Herzog, H. Kibbel, T. Hackbarth, DaimlerChrysler Forschungsinstitut Ulm, Ulm, GERMANY.

Strain relaxed $Si_{1-x}Ge_x$ layers on Si(100) substrates are important for the use as buffer layers for $Si/Si_{1-x}Ge_x$ quantum well structures. They allow the growth of heterostructures with Si layers strained in tension, which provide sufficiently large conduction band offsets for two dimensional transport of electrons in quantum well devices. In this contribution we report on the strain relaxation of pseudomorphic $Si_{1-x}Ge_x$ on Si(100) with Ge concentrations varying from x = 0.1 to 0.3 after hydrogen implantation and annealing. The pseudomorphic layers were grown by molecular beam epitaxy. Their thicknesses were chosen close to their critical thicknesses for pseudomorphic growth. Rutherford backscattering, He ion scattering, X-ray diffraction and transmission electron microscopy were used to characterize the samples after growth and after strain relaxation. Hydrogen implantation was performed with various energies and dose. Low energy hydrogen implants (5 - 30 keV) with a dose of typically 3 x 10^{16} H^+cm^{-2} and subsequent thermal annealing below 600° C produces initially oblate hydrogen bubbles at the mean range of the hydrogen ions. Best results were obtained when the hydrogen bubbles were located slightly below the $Si_{1-x}Ge_x$/Si interface. Anneals at temperatures >700°C lead to strain relaxation of the $Si_{1-x}Ge_x$ layers. Using this new approach, the threading dislocation density in the strain relaxed Si-Ge layers could be kept below 10^7cm^{-2} for x < 0.21. We propose a model for the hydrogen induced strain relaxation mechanism assuming the formation of short misfit dislocation segments from dislocation loops punched out by hydrogen filled nanocracks. The conditions for efficient strain relaxation are derived and discussed.

10:45 AM O7.7
TEM STUDY OF EXTENDED DISLOCATION FORMATION IN SiGe SUPERLATTICE FILMS. Tamara Radetic, Ronald Gronsky, UC Berkeley, Dept. of Mater. Sci. & Minrl. Engr., Berkeley, CA; Jianlin Liu, Kang L. Wang, UCLA, Dept. of Elect. Eng., Los Angeles, CA; Mark S. Goorsky, Caroline D. Moore, Dept. of Mater. Sci. & Engr., Los Angeles, CA.

Defects in a $Si_{0.6}/Ge_{0.4}$ superlattice film and its underlying buffer layer have been investigated. The buffer layer, grown on a {100} Si substrate, consists of two components: a continuously graded $Si_{1-x}Ge_x$ (x≤0.5) layer, and a relaxed capping layer ($Si_{0.5}Ge_{0.5}$). In addition to the conventional network of misfit dislocations, predominantly 60° in character, and common threading dislocations, a number of extended dislocations and overlapping stacking faults appear in the buffer layer. The capping layer shows a relatively low dislocation density, but most of the threading dislocations appear to be dissociated. This configuration is unexpected, since x-ray measurements confirm the existence of approximately 7-8% residual compressive strain in the capping layer, which should be sufficient to suppress dislocation dissociation. However, overlapping stacking faults can lead to the formation of twins within the buffer layer, which can further propagate into the film. The effects of local microsegregation and local strain fields on the structural reconfiguration of these defects are also revealed.

11:00 AM O7.8
STRUCTURE AND MORPHOLOGY OF EPITAXIAL SiGe FILMS DEPOSITED ON Si-ON-INSULATOR SUBSTRATES*. P. Moran, D.E. Savage, E.Rehder, P. Rugheimer, M.G. Lagally, T.F. Kuech, University of Wisconsin, Madison, WI; W.I. Wang, Columbia University, New York, NY. *Supported by NSF-MRSEC

Si-on-insulator (SOI) substrates are increasingly important in semiconductor devices, in part because of their superior electrical isolation. In addition, SOI substrates have been investigated as compliant substrates in heteroepitaxial growth. Low-defect-density strain-relaxed SiGe deposited on SOI would be excellent for fabrication of high speed FET's. Key issues are maintaining film smoothness and reducing the defect density near the surface. In this study we compare film structure and morphology of heteroepitaxial SiGe films grown with MBE and CVD on SOI substrates. The substrates were produced by smartcut and subsequent wafer bonding and had a top Si(001) template thinned by oxidation to 3 to 16 nm, a buried oxide layer of 100nm, and a Si(001) handle wafer. Films grown by MBE at 500C and measured with AFM were much smoother (∼3nm rms roughness) than films grown by UHV-CVD (∼30nm rms roughness). The strain distribution measured with high-resolution XRD was narrower in the MBE grown films as well. These differences will be discussed in terms of the kinetics of growth in both techniques as well as the inherent role hydrogen plays in CVD of SiGe.

11:15 AM O7.9
SiGe RELAXED BUFFER LAYERS GROWN AT VERY HIGH RATES. C. Rosenblad[1], M. Kummer[1], E. Müller[1], J. Stangl[2], G. Bauer[2], and H. von Känel[1]; [1]Laboratorium für Festkörperphysik, ETH-Zürich, Zürich, SWITZERLAND; [2]Institut für Halbleiterphysik, Johannes Kepler Universität Linz, Linz, AUSTRIA.

Virtual SiGe substrates with lattice constants ranging from a_{Si} to a_{Ge} can be synthesized on a Si substrate using compositionally graded relaxed buffer layers. For commercial applications, however, these buffer layers suffer from the major drawback, that the deposition time using conventional growth techniques amounts to several hours, as a result of which no attempts have yet been made to initiate a production of devices based on such virtual substrates. We have developed a new growth technique, called low-energy plasma enhanced chemical vapour deposition (LEPECVD), for the growth of SiGe heteroepitaxial systems at the very high rates of at least 5 nm/s. We shall show that despite the high growth rate, the buffer layers are completely relaxed (residual in-plane strain $\epsilon_{||} < 0.1\%$) with etch pit densities below 10^5 cm^{-2} for buffers graded linearly up to 30% Ge. This compares to state-of-the-art relaxed buffers grown by conventional growth techniques in various laboratories at growth rates one to two orders of magnitude lower. The structural quality of the buffers will be discussed based on characterization by X-ray reciprocal space mapping, cross-sectional transmission electron microscopy, defect etch pit counting and on low temperature electrical transport measurements of modulation doped strained Si channels grown on the buffer layers.

SESSION O8: SOLID-PHASE RECRYSTALLIZATION AND EPITAXY
Chair: David H. Matthiesen
Thursday Afternoon, December 2, 1999
Harvard (M)

1:30 PM *O8.1
Ni-INDUCED SELECTIVE NUCLEATION AND SOLID PHASE EPITAXY OF LARGE-GRAINED POLY-Si ON GLASS. Rosaria A. Puglisi, Claudine Chen, Hiroshi Tanabe, Harry A. Atwater, Thomas J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA; E. Rimini, Universita' di Catania, Dipartimento di Fisica, and Unita INFM, Catania, ITALY.

We report the synthesis and characterization of very large-grained polycrystalline Si films with controlled defect microstructure on glass substrates via selective nucleation and solid phase epitaxy (SNSPE). Applications in low-cost thin film crystalline Si photovoltaics demand the use of low-cost substrates such as soda-lime glass which constrains process temperatures. In SNSPE, selective crystallization of an initially amorphous Si template film at lithographically predetermined sites enables grain sizes much larger than those observed via random crystallization of amorphous Si or vapor deposition on the glass substrate, and the process is compatible with the softening temperature of glass. Selective heterogeneous nucleation in 100 nm thick amorphous Si films was achieved by Ni-induced crystallization from patterned 5 micron diameter Ni rich seed regions. During annealing between 500 and 610 C, seeded crystallization begins at the seed regions and continues via a lateral solid phase epitaxy process whose rate is enhanced by the presence of nickel disilicide precipitates at the amorphous Si-crystal Si interface. Upon complete crystallization, grain sizes of up to 40-50 microns in diameter are obtained. Ni-induced crystallization leads to a large grain size with a needle-like subgrain structure of low-angle boundaries with a length scale of 10-100 nm. The maximum achievable grain size depends on the product of the solid phase epitaxy rate and the incubation time for spontaneous nucleation. We have studied the variation of the solid phase epitaxy rate and the incubation time with Ni concentration in the nucleation seed region, and determined an optimal doping concentration for largest grain size. The 100 nm large-grained polycrystalline Si films were then used as templates for epitaxial growth at 500-550 C of thicker (> 1 micron thick) Si films. Morphological and structural aspects of the epitaxial Si layers, and in particular the relation of the defect density in the epitaxial film to the template defect density will be discussed, as will be measurements of key photovoltaic quantities such minority carrier lifetime and diffusion length.

2:00 PM O8.2
SOI FORMATION FROM AMORPHOUS SILICON BY MILC AND HIGH TEMPERATURE ANNEAL. M.C. Poon, M. Qin, W.Y. Chan, C.Y. Yuen, S. Shivani, M. Chan, S. Jagar, P. K. Ko, Hong Kong University of Science & Technology, Dept. of Electrical and Electronic Engineering, HONG KONG; H. Wong, City University of Hong Kong, Dept. of Electronic Engineering, HONG KONG.

Metal-Induced-Lateral-Crystallization (MILC) has been used to enlarge the grain size and improve the quality of polysilicon Thin-Film-Transistor (TFT). However, the MILC temperature is still low and the grain size is still not desirable. We have studied the feasibility of forming very large grains (single crystal like) from amorphous silicon (Si) by combining MILC on amorphous silicon and subsequent high temperature treatment. 3000 Å of oxide was grown on Si substrate by wet oxidation at 1000°C, followed by the deposition of 1000 Å of a-Si at 550°C. A 3000 Å of LTO layer was then deposited at 425°C, and windows were patterned next to the desired region for crystallization. Thin nickel (Ni) was then deposited and MILC was carried out subsequently at 500-560°C for 0-30 hours in N_2 ambient. The poly-Si region formed by the MILC was found to be around 0-150 um. The Ni film and the LTO were then removed and the MILC poly-Si was further annealed at 900-1300°C for 0-2 hours. After annealing, we found that the size of the crystal is remarkably enhanced and can reach the order of several ten's of micron. We have also studied the effect of the MILC and anneal temperature and time, the Ni thickness and size, and other parameters to maximize the grain size and quality. Our preliminary results have also shown that the transistor formed on the large enhanced grain has I-V characteristics close to transistor fabricated on SIMOX wafer. This new technology can be a promising alternative method for silicon-on-insulator (SOI) formation. For the advance technology comes with device scaling, it is possible to individually recrystallize the active region of each transistor, giving TFT (as the way it is formed) with SOI MOSFET performance.

2:15 PM O8.3
STRAIN MODIFICATION OF EPITAXIAL $SrRuO_3$ FILMS USING STRUCTURAL TRANSITIONS OF FERROELECTRIC $BaTiO_3$

SUBSTRATE. M.K. Lee, T.K. Nath and C.B. Eom, Department of Mechanical Engineering and Materials Science, Duke University, Durham, NC; M. Smoak and F. Tsui, Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC.

Electrical conduction and magnetic behavior of ferromagnetic $SrRuO_3$ (Tc=150K) were tuned systematically using the structural transitions of ferroelectric $BaTiO_3$ as the growth template. Large resistivity changes of $SrRuO_3$ were observed at the structural transition temperatures of the $BaTiO_3$ substrate. The observed effect appears to originate from the lattice changes of $BaTiO_3$ (cubic to tetragonal at 393K, tetragonal to orthorhombic at 278K and orthorhombic to rhombohedral at 183K) induced by an expansion of spontaneous polarization axis. The resistivity and the magnetization were measured as a function of temperature from 5 to 400 K. The interplay between the electrical conduction and magnetization changes and the biaxial strain of $SrRuO_3$ caused by the distortions of $BaTiO_3$ substrate. The observed phenomenon will be very useful for the fabrication of novel perovskite oxide devices. This work was supported by NSF Grant No. DMR-9802444, the NSF Young Investigator Award and the David and Lucile Packard Fellowship (CBE).

2:30 PM O8.4
SPM CHARACTERIZATION OF SUBSTRATE SURFACES PREPARED FOR CARBON-RELATED-FILM DEPOSITION. Kazumasa Narumi and . Hiroshi Naramoto, JAERI, Advanced Science Research Center, Takasaki, Gunma, JAPAN; Shunya Yamamoto, JAERI, Dept of Materials Development, Takasaki, Gunma, JAPAN.

Since the establishment of diamond growth by chemical vapor deposition (CVD), extensive investigation into diamond thin film has been done by many groups. However, sufficiently uniform epitaxial film has not been obtained. Although it might be important for epitaxial growth, special attention does not seem to have been paid to preparing the substrate. We are investigating the preparation of the substrate from the view point of possibility of the epitaxial growth of diamond. In the present study, sapphire and SiC substrates were processed under various conditions and surface topography was investigated by scanning probe microscopy. The sapphire substrates were annealed under an oxidizing or reducing atmosphere at 1000°C to 1400°C for 1 to 10 hours. After the annealing, surface topography was observed with an atomic force microscope (AFM). For the substrates annealed in open air, atomically smooth surfaces which consist of terraces and atomic steps were observed. The shape of the terrace is dependent on the annealing temperature. The situation is different for the substrates annealed in a reducing atmosphere. In the meeting, the results, together with those for SiC, will be discussed in detail.

2:45 PM O8.5
EFFECT OF ELECTRIC FIELD ON METAL INDUCED LATERAL CRYSTALLIZATION OF AMORPHOUS SILICON. S. Shivani, M.C. Poon[1], M. Qin, W.Y. Chan, C.Y. Yuen, H.Wong, [1]Dept of Electrical and Electronic Engineering, Hong Kong Univesity of Science & Technology, Sai Kung, Hong Kong; Dept of Electronic Engineering, City University of Hong Kong, Kowloon Tong, HONG KONG.

In current Thin Film Transistor (TFT) technology, Metal (Nickel)-Induced-Lateral-Crystallization (MILC) has been used to enhance the grain size and quality of the poly-Si formed from amorphous Si. However, crystallization by MILC takes long time since the velocity is determined mainly by diffusion of nickel silicide. Moreover, the crystal orientation is not controllable. In this work, we study the low temperature, high speed and high quality crystallization of Si by electric-field-assisted MILC (EMILC). 3000 Å of oxide was thermally grown on (100) p-Si. 1000Å of amorphous Si was deposited by LPCVD at 550°C, followed by 1000Å of LTO at 425°C. Window patterns were defined and thin nickel film was deposited followed by electrodes formation. We have found that the velocity of EMILC is much faster than that of MILC. For an electric field of 53.5V/cm, the lateral crystallization velocity was 19.2 μm/h at 560°C as compared to 7.2μm/h in the case of MILC. At 500°C, the lateral crystallization velocity was 1.2μm/h as compared to 0.2 μm/h for MILC region. The directionality of the resulting crystallization depended on the polarity of the electric field. Compared to MILC, the crystallization velocity of the negative electrode side was much faster while that of the positive electrode side was retarded. From microscopy and micro-Raman, compared to MILC, the poly-Si formed from EMILC has much better uniformity and crystallinity. Our preliminary results have also shown that the TFTs formed on the EMILC poly-Si have much better I-V characteristics and performance than those from MILC. EMILC can greatly lower the process time and temperature and can be applied in poly-Si TFT on glass substrates and many other areas. Moreover, the better uniformity and directional crystallization will be advantageous for the development of future novel devices.

3:00 PM O8.6
POROUS SiC SUBSTRATE MATERIALS FOR HIGH-QUALITY EPITAXIAL AND BULK GROWTH. M. Mynbaeva, N. Savkina, D. Davidov, A. Zubrilov, A. Strel'chuk, A. Tregubova, A. Lebedev, Ioffe Institute, St. Petersburg, RUSSIA; I. Kotousova, N. Seredova, Crystal Growth Research Center, St. Petersburg, RUSSIA; V. Dmitriev, TDI, Inc., Gaithersburg, MD.

SiC devices are on the pre-production stage. A few companies including Siemens, ABB, Northrop Grumman, and Cree Research have demonstrated very impressive results on SiC devices. The main unsolved problem in SiC technology is a high density of defects in substrate materials (micropipes and dislocations) propagating into device structures and causing device failure. Recently, significant progress in defect density reduction in semiconductor materials has been achieved using lateral overgrowth technique. In this paper, we describe a novel technique, which shows a high potential for defect reduction in epitaxial and bulk SiC. This technique is based on nano-scale epitaxial lateral overgrowth (NELOG) method, which employs porous substrate materials. SiC layers were grown on porous SiC by sublimation. Porous SiC substrates were formed by surface anodization of SiC commercial wafers. Pore's size was in nm scale range. It is important that NELOG technique does not require any mask. This technique may be easily scaled for large area substrates. It was shown that SiC layers grown on porous SiC substrates have smooth surface and high crystal quality. The surface of overgrown material was uniform and flat without any traces of porous structure. Background doping concentration in the epitaxial SiC layers was reduced by an order of magnitude by growing on the porous substrates (the minimum Nd-Na concentration of 8E14 per cubic cm was measured). X-ray topography indicated significant defect density and stress reduction in SiC grown on porous material. The FWHM of x-ray rocking curve of 6 arcsec was measured. Photoluminescence measurements showed a reduction of deep level concentration in SiC. Results of detailed characterization of SiC material grown on porous SiC will be presented.