19th International Conference on Molecular Beam Epitaxy

4th – 9th September 2016

Le Corum

Montpellier

FRANCE

Final program

Instructions to authors

Oral presentations

The time allotted to each oral presentation will be:

- **Plenary talks : 50 min. (including 5 – 10 min. discussion)**
- **Invited talks : 30 min. (including 5 min. discussion)**
- **Contributed papers : 20 min. (including 3 min. discussion)**

LCD projectors and conference PCs (OS: Windows 7 or 10) are available in each room. PowerPoint 2010, and Acrobat Reader are installed on the PCs. Therefore, the speakers are requested to bring a Windows 7 compatible Adobe pdf file or a power point file on memory stick or CD. Please upload in a folder labeled your session number and check your presentation on the conference PC in advance, preferably the day before your session. Please use your program number and your family name as the presentation file name.

It is also possible to connect your own PC to the projector, however it may not project your slides properly on the screen if the screen resolution of your PC does not match to the conference projector. We recommend you to connect your PC and check your presentation on the screen in advance, preferably the day before your session. Do not forget to bring your own conversion cable if you use PC with HDMI interface, Apple PC, and so on.

Poster presentations

The poster sessions will take place in ***Espace Antigone*** (see map), next to the exhibition, on Monday 5th September and Tuesday 6th September, from 4 pm to 6 pm. The posters have to be displayed before 4 pm on the day of presentation.

The poster boards are consecutively numbered, and presenters are requested to post their poster according to the allotted number given in the poster session part of the program.

The size of the posters should not exceed 1.18 m x 0. 96 m. **Poster orientation is portrait**.

Publication of the proceedings

The proceeding of IC-MBE 2016 will be published as a special issue of Journal of Crystal Growth, an electronic version of which will be sent to every registered conference participant.

Authors of accepted abstracts may submit a formal manuscript by October 30, 2016. All submitted papers must be clearly written in excellent English and contain only original work, which has not been published by or is currently under review for any other journal or conference.

All papers will be peer-reviewed by independent reviewers following the standards of Journal of Crystal Growth.

Instructions for submission:

- All manuscripts and any supplementary material should be submitted through Elsevier Editorial System (EES) located at: http://ees.elsevier.com/crys/default.asp
- Make sure to select "**SI: CRYS_MBE 2016**" when reaching the "Article Type" step in the submission process.
- Papers must not exceed 6 pages (one-column, at least 11pt fonts) including figures, tables, and references. A detailed submission guideline is available as "Guide to Authors" at: http://www.journals.elsevier.com/journal-of-crystal-growth.

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ORAL SESSIONS

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Auditorium Pasteur

8:30-8:50

Opening

8:30 – 8:50

Plenary 1 – 8:50-9:40

Quantum dot light sources: Present and future

Yasuhiko Arakawa
Institute of Industrial Science, The University of Tokyo, Tokyo, Japan

8:50-9:40

Recent advances in quantum dot growth technology have led to the commercialization of quantum dot lasers for telecommunications and other applications. Moreover, single quantum dots coupled to photonic crystal nanocavities have enabled the investigation of fundamental physics such as solid-state cavity-QED. In this presentation, we discuss the current state of the art of InAs/GaAs quantum dot lasers, and also future prospects including their application to hybrid silicon photonics and the development of ultra-small nanolasers. We also describe the demonstration of a single photon emission from a III-Nitride nanowire-based quantum dot operating above room temperature.

Plenary 2 9:40-10:30

Functionality by design or default? Establishing meaningful structure-property relationships using MBE-grown oxide films

Scott A. Chambers
Physical and Computational Sciences Directorate, Pacific Northwest National Laboratory, Richland, WA, USA

9:40-10h:30

As a broad class of materials, complex metal oxides exhibit an exceedingly diverse range of properties in every category – electronic, optical, magnetic and chemical. And since most metals across the periodic chart react with oxygen, the number of stable oxide compounds is enormous. These attributes create tremendous opportunity *and* significant challenges for the oxide film grower. Understanding *what* nucleates, and what the *actual* properties are, can be very challenging. As we shall see in this lecture, MBE plays a unique and powerful role in sorting out fact from fiction in this scientific enterprise, and has led to the discovery of some fascinating new materials systems.

Auditorium Pasteur

10:30-11:00

Coffee break
10:30 - 11:00

Plenary 3 11:00-11:50

Designing Dirac states in HgTe by MBE

Christoph Brüne
Physikalisches Institut, Universität Würzburg, Würzburg, Germany

11:00-11:50

HgTe in its bulk state is a semimetal with an inverted band structure. This band inversion gives rise to the existence of previously unknown states of matter in this kind of material. HgTe is a very interesting system to investigate these new states since it can be MBE grown with high crystalline quality and changes in the growth influence the material properties profoundly. In this way HgTe can be used to realize Dirac Fermions in 1, 2 or 3 dimensions with the most prominent examples being the quantum spin Hall state, 3-dimensional topological insulators and Weyl Fermions.

11:50 – 12:20

Photo
11:50 – 12:20

12:20 – 13:40

Lunch
12:20 – 13:40

Room A – MBE Fundamentals

13:40-14:10

Mo-A1

Growth and optical properties of quantum dots for quantum nanophotonics

Allan Bracker(1), Michael Yakes(1) Lily Yang(2) Sam Carter(1), Mijin Kim(3), Chul Soo Kim(1), Patrick Vora(2), Tim Sweeney(2), Brennan Pursely(2) Joel Grim(1), Dan Gammon(1)

1 - Naval Research Laboratory, Washington, DC 20375 USA, 2 - NRC Research Associate at Naval Research Laboratory, Washington, DC 20375 USA, 3 - Sotera Defense Solutions, Inc., Annapolis Junction, Maryland 20701 USA

Quantum dots can be grown readily through self-assembly by molecular beam epitaxy but with only primitive control over spatial dimensions and composition. Potential applications that aim to directly harness quantum mechanical effects require a more demanding combination of growth control, heterostructure design, and device fabrication to really achieve the full potential of self-assembled dots. Recent advances have taken impressive steps towards quantum devices. This presentation considers the issues of quantum dot growth, position control, and heterostructure design for devices based on membrane photonic crystals and mechanical oscillators.

14:10-14:30

Mo-A2

Selective area growth of in-plane InAs nanowires on GaAs (001) using Atomic Hydrogen-Assisted Molecular Beam Epitaxy

M. Fahed(1), L. Desplanque(1), D. Troadec(1), Y. Wang(2), P. Ruterana(2), G. Patriarche(3), X. Wallart(1)

1 - Institute of Electronics, Microelectronics and Nanotechnology, CNRS and University of Lille, Avenue Poincaré, CS 60069, 59652 Villeneuve d'Ascq Cedex, France, 2 - CIMAP UMR 6252 CNRS-ENSICAEN-CEA-UCBN, 6, Boulevard du Maréchal Juin, 14050 Caen Cedex, France, 3 - LPN-CNRS, Route de Nozay 91460 Marcoussis, France

The selective area growth of in-plane InAs nanowires via GaSb nano-templates on a GaAs (001) substrate by molecular beam epitaxy (MBE) is reported. The selective growth of GaSb inside 100 nm wide stripes oriented along [110] or [1-10] in a SiO_2 mask layer is achieved at low temperature thanks to the use of an atomic hydrogen flux during the growth. The impacts of the nano-stripe direction and of the Sb/Ga flux ratio on the strain relaxation of GaSb are demonstrated. We then show how these GaSb templates can be used to grow in-plane InAs nanowires on top.

14:30-14:50

Mo-A3

Modeling the metal incorporation during MBE growth of the oxide semiconductors Ga_2O_3, In_2O_3, and their alloy $(In_xGa_{1-x})_2O_3$

Patrick Vogt and Oliver Bierwagen

Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5–7, D-10117 Berlin, Germany

This contribution presents the modeling of the reaction kinetics of the oxide semiconductors Ga_2O_3, In_2O_3, and their alloy $(In_xGa_{1-x})_2O_3$. The metal incorporation as a function of all experimental parameters, i.e. growth temperature, metal-, and oxygen fluxes is presented. Experimentally, it turns out, that – despite their common stoichiometry – the metal incorporation evolutions of Ga_2O_3 and In_2O_3 are different. The Ga incorporation remains the same when ternary grown as $(In_xGa_{1-x})_2O_3$, whereas, the In incorporation is in total contrast when grown as $(In_xGa_{1-x})_2O_3$ compared to In_2O_3. The reaction kinetics and its physical origin for all mentioned compounds is described and explained by our model.

Room B – Wide Bandgap semiconductors

13:40-14:00

Mo-B1

Selective area sublimation: a new method for the fabrication of (In)GaN nanostructures

B. Damilano, S. Vézian, B. Alloing, M. Portail, J. Brault, V. Brändli, J. Massies

CRHEA-CNRS, Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications, Centre National de la Recherche Scientifique, Rue B. Gregory, 06560 Valbonne, France

A fraction of a SiN_x mono-layer is formed on a GaN layer by exposing the surface to a Si flux. When the sample is heated under vacuum at high temperature (900°C), we observe the sublimation of GaN in the regions uncovered by the thermally resistant SiN_x mask. This selective area sublimation (SAS) process can be used for the formation of nanopyramids and nanowires with a diameter down to 4 nm. Also, if InGaN quantum wells are included in the structures before sublimation, InGaN quantum disks with quasi identical sizes in the 3 dimensions of space can be formed using SAS.

14:00-14:20

Mo-B2

Selective Area Growth of Regularly Arrayed AlGaN Nanocolumns

J. Yoshida(1), T. Kano(1), Y. Matsui(1), T. Oto(1), K.Kishino(1)(2)

1 - Department of Engineering and Applied Sciences, Sophia University, 7-1 Kioi-cho, Chiyoda-ku, Tokyo 102-8554, Japan, 2 - Sophia Nanotechnology Research Center, Sophia University, 7-1 Kioi-cho, Chiyoda-ku, Tokyo 102-8554, Japan

Nitride nanocolumns (NCs) have great emission properties, such as dislocation-free nature, strain relaxation in active layer, and high light extraction efficiency. We have developed selective area growth (SAG) of regularly arranged InGaN/GaN NCs using Ti-mask. By use of this technique, we have demonstrated monolithic integration of light emitting diodes (LEDs) with different emission colors [and photonic crystals (PCs). The PCs are utilized to obtain surface emitting lasing operation and directional light beam radiation of LEDs. It is necessary to use AlGaN NCs for ultraviolet LEDs (UV-LEDs) and AlGaN cladding layers for InGaN-based nanocolumn lasers. However, a high sticking coefficient of Al adatoms on the Ti-mask surface discourages from SAG of AlGaN NCs.In our previous report, the SAG of AlGaN NCs with a lattice constant(*L*) of 200 nm has been achieved using nano-templates. In this study, we demonstrate the Ti-mask SAG of AlGaN NCs, observing UV LED emission.

14:20-14:50

Mo-B3

Al(Ga)N Nanowire Deep Ultraviolet Light Emitting Diodes and Lasers

S. Zhao(1), X. Liu(1), S. Y. Woo(2), M. Bugnet(2), G. A. Botton(2), and Z. Mi(1)

1 - Department of Electrical and Computer Engineering, McGill University, 3480 University Street, Montreal, Quebec H3A 0E9, Canada, 2 - Department of Materials Science and Engineering and Canadian Centre for Electron Microscopy, McMaster University, 1280 Main Street West, Hamilton, ON L8S 4M1, Canada

We report on the molecular beam epitaxy of Al-rich Al(Ga)N nanowire heterostructures, their structural, optical and electrical characterization, and device applications. The emission wavelengths can be controllably tuned in the UV-B and UV-C bands. At room temperature, the internal quantum efficiency reaches around 80%. Al(Ga)N nanowire LEDs operating in the wavelength range of 200nm to 360nm have been demonstrated, which exhibit excellent electrical and optical performance. With the use of such defect-free Al(Ga)N nanowire arrays, electrically pumped lasers have been achieved in the UV-B and UV-C bands for the first time. At room temperature, the threshold current is well below 1 mA.

Room C – Nanostructures: Nanowires

Notes

13:40-14:00

Mo-C1

Micro-photoluminescence and cathodoluminescence study of single-photon emitters in core-shell nanowires

L. Francaviglia(1), F. Matteini(1), G. Tütüncüoglu(1), H. Potts(1), J. Arbiol(2), A. Fontcuberta iMorral(1)

1 - École Polytechnique Fédérale de Lausanne, STI IMX LMSC, 1015 Lausanne, Switzerland, 2 - Institut Català de Nanociència i Nanotecnologia, Campus UAB ICN2, 08193 Barcelona, Spain

The performance of quantum dots as deterministic single-photon emitters can be enhanced by embedding them in nanowires that, e.g., act like waveguides. Recently we have found that quantum dots can form in AlGaAs shells of nanowires, resulting in bright single-photon emitters in GaAs-AlGaAs core-shell nanowires. The formation mechanism of these quantum dots is still not well understood. In this context, micro-photoluminescence and cathodoluminescence represent powerful tools to non-destructively investigate the quantum-dot characteristics on a large ensemble. In particular, here we show that a correlation between the quantum-dot occurrence and the nanowire shell thickness allows to control their density and that the emission energy shifts along single nanowires.

14:00-14:20

Mo-C2

Effect of surface passivation on the optical properties of catalyst free GaAsP nanowires

C. Himwas(1)(2), G. Patriarche(2), F. Oehler(2), S. Collin(2), J.-C. Harmand(2), M. Tchernycheva(1)

1 - Institut d'Electronique Fondamentale (IEF), UMR 8622 CNRS, Université Paris-Saclay, F-91405 Orsay cedex, France, 2 - Laboratoire de Photonique et de Nanostructures (LPN), CNRS, Université Paris-Saclay, Route de Nozay, F-91460 Marcoussis, France

In this work, we report structural and optical characteristics of catalyst-free GaAsP nanowires grown by solid-source molecular beam epitaxy. The phosphorus content was adjusted to obtain a peak emission energy at ~1.7 eV, to serve for high-efficiency GaAsP/Si two-junction tandem solar cells. In order to minimize non-radiative surface recombination and thereby improve the luminescence yield of the GaAsP nanowires, a thin shell of higher bandgap material was epitaxially grown on the lateral surface. We vary the thickness and composition of the shell and find that the best passivation is achieved fora 6-nm GaP shell. The luminescence intensity of such GaAsP/GaP core/shell nanowires was enhanced by ~50times in comparison with that of a bare GaAsP core.

14:20-14:40

Mo-C3

The double role of Ga droplets in the self-catalyzed growth of GaAs nanowires on SiO_x/Si(111) substrates

T. Tauchnitz(1)(2), H. Schneider(1), M. Helm(1)(2), E. Dimakis(1)

1 - Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics& Materials Research, Bautzner Landstraße 400, 01328 Dresden, Germany, 2 - cfaed, Technische Universität Dresden, 01062 Dresden, Germany

We have investigated the in-situ surface modification of a SiO_x/Si(111) substrate by Ga droplets and its effect on the subsequent self-catalyzed growth of GaAs nanowires. Using a procedure of Ga droplet formation and subsequent re-evaporation prior to the nanowire growth, we found that the number density of nanowires at a given growth temperature can be varied deliberately within four orders of magnitude without affecting the nanowire diameter. A detailed study of the Ga droplet formation in a wide range of substrate temperatures revealed the physical processes that control the number density and size of the droplets.

14:40-15:00

Mo-C4

Effects of Sb on Crystal Phase, Morphology and Optical Emission of Self-catalyzed GaAsSb Nanowires on Si(111) and Graphitic Substrate

D. Ren(1), D. L. Dheeraj(2), J. S. Nilsen(3), J. Huh(1), A. Gustafsson(4), A. T. J. van Helvoort(3), H. Weman(1) and B. O. Fimland(1)

1 - Department of Electronics and Telecommunications, Norwegian University of Science and Technology (NTNU), NO-7491, Trondheim, Norway, 2 - 2: CrayoNano AS, Otto Nielsens vei 12, NO-7052, Trondheim, Norway, 3 - Department of Physics, Norwegian University of Science and Technology (NTNU), NO-7491, Trondheim, Norway, 4 - Solid State Physics and NanoLund, Lund University, Box 118, SE-22100 Lund, Sweden

Ternary nanowires (NWs) with bandgap tunability are of great interest for nano-optoelectronic applications. In this study, we report on significant Sb-induced effects on crystal phase, morphology and optical emission of a self-catalyzed GaAsSb NW array. The growth mechanism is studied with thermodynamic, kinetic and density functional theory analysis. The results explain the morphological evolution and the crystal phase transition by Sb incorporation into the GaAs NWs. Moreover, the optical characterizations demonstrate good optical emission tunability for these ternary NW arrays. With the obtained understanding of the growth mechanism, we obtain high-yield growth of GaAsSb NWs on graphitic surfaces for the first time.

	Room A – MBE Fundamentals	Room B – Wide Bandgap semiconductors
14:50-15:10	**Mo-A4** **Growth of Atomically flat (111)A Ga(Al)As surfaces** Luca Esposito(1), Sergio Bietti(2), Andrea Ballabio(1), Alexey Fedorov(3), Richard Noetzel(2) and Stefano Sanguinetti(2) *1 - LNESS and Dipartimento di Fisica, Politecnico di Milano, Milano (Italy), 2 - LNESS and Dipartimento di Scienza dei Materiali, Università di Milano-Bicocca, Milano (Italy), 3 - LNESS and IFN–CNR, Milano, (Italy)* We will present: i) a systematic study to identify prominent adatom incorporation mechanisms, ii) the model we built to interpret and control the growth along this (111)A crystallographic direction and iii) the growth procedure we used to obtain an atomically flat Ga(Al)As (111)A surfaces. Very narrow GaAs/AlGaAs quantum well emission linewidth will be also demonstrated.	**Mo-B4** **Self-Assembled Growth of Single Crystalline GaN Nanowires on a Flexible Ti Foil** G. Calabrese, P. Corfdir, G. Gao, C. Pfüller, A. Trampert, O. Brandt, L. Geelhaar, S. Fernández-Garrido *Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany* We demonstrate the self-assembled growth of single crystalline and mainly vertically oriented GaN nanowires directly on a flexible Ti foil by plasma-assisted molecular beam epitaxy. High-resolution transmission electron microscopy indicates that their structural quality is comparable to that of nanowires grown on Si substrates. Low-temperature photoluminescence spectroscopy reveals the presence of basal-plane stacking faults and a lower density of inversion domain boundaries than in the case of GaN nanowires on Si. The room-temperature photoluminescence spectrum of GaN nanowire ensembles grown on a Ti foil is not influenced or degraded by the bending of the substrate.	14:50-15:10
15:10-15:30	**Mo-A5** **Monitoring Surface Roughness Using RHEED Intensity Oscillations** Wolfgang Braun and Jochen Mannhart *Max Planck Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany* Separation of the high- and low-frequency components of RHEED intensity oscillations during pulsed deposition allows us to extract a signal that is in phase with the cyclic surface morphology evolution during layer-by-layer growth. Similar to a capacitance measurement, the periodic modulation of surface roughness on a time scale smaller than the period of layer-by-layer growth probes the differential response of the growth front to changes in step density. This signal does not follow the complex variation of the RHEED oscillation phase with diffraction conditions and surface reconstruction and allows a direct detection of monolayer completion.	**Mo-B5** **Epitaxy of GaN Nanowires on Graphene** V. Kumaresan(1), L. Largeau(1), A. Madouri(1), F. Glas(1), H. Zhang(2), F. Oehler(1), A. Cavanna(1), A. Babichev(2)(3), N. Gogneau(1), M. Tchernycheva(2), J-C. Harmand(1) *1 - Laboratoire de Photonique et de Nanostructures (LPN), CNRS, Université Paris-Saclay, Route de Nozay, F-91460 Marcoussis, France, 2 – Institut d'Electronique Fondamentale, UMR 8622 CNRS, University Paris Sud, University Paris-Saclay, 91405 Orsay cedex, France, 3 - ITMO University, St. Petersburg 197101, Russia* We demonstrate the epitaxial growth of GaN nanowires on graphene using molecular beam epitaxy without any catalyst or intermediate layer. Growth is highly selective with respect to silica which surrounds the graphene layer. The nanowires grow vertically along their c-axis and we observe a unique epitaxial relationship between the graphene honeycomb and the GaN hexagonal lattices. Remarkably, nanowire density and height both decrease when the number of graphene layers underneath increases. We propose a model explaining the nanowire density variation. The crystalline structure of the GaN nanowire is defect-free and they present good optical properties. This demonstrates that graphene on an amorphous carrier substrate is a promising alternative to bulk crystalline substrates for growing high quality epitaxial GaN nanostructures.	15:10-15:30
15:30-16:00	Coffee break 15:30 – 16:00	Coffee break 15:30 – 16:00	15:30-16:00
16:00-18:00	Poster session 16:00 – 18:00	Poster session 16:00 – 18:00	16:00-18:00

Notes

15:00-15:30

Mo-C5

Monolithic integration & epitaxial gain control of GaAs-based nanowire lasers on Si

G. Koblmüller(1), B. Mayer(1), T. Stettner(1), B. Loitsch(1), M. Kaniber(1), G. Abstreiter(1)(2), J. J. Finley(1)

1 - Walter Schottky Institut, & Physik Dept., TU Munich, 85748 Garching, Germany, 2 - Institute for Advanced Study, TU Munich, 85748 Garching, Germany

We present our recent highlights on monolithically integrated GaAs-nanowire lasers on silicon and further demonstrate capabilities in epitaxial gain control to tune threshold power density and lasing wavelength. Importantly, the investigated NW lasers reveal high spontaneous emission coupling factors (beta-factor) of ~0.2, and ultrafast temporal emission down to < 3 ps, equivalent to repetition rates of > 250 GHz. Introduction of coaxial multiple-quantum wells in the NW lasers allows to tune threshold power density, opening a gateway for advanced epitaxial gain control. Ultimately, we also demonstrate continuous-wave lasing under optical excitation and further show preliminary results of integration and coupling to SOI waveguides.

15:30-16:00

Coffee break
15:30 – 16:00

16:00-18:00

Poster session
16:00 – 18:00

Room A – MBE grown Devices

8:30-9:00

Tu-A1

Status and perspectives of MBE for GaN electron devices on Silicon

Y. Cordier(1), S. Rennesson(1), R. Comyn(1)(2), E. Frayssinet(1)

1 - CRHEA-CNRS UPR10, rue Bernard Grégory, 06560 Valbonne, France, 2 - LN2-CNRS UMI-3463, Université de Sherbrooke, Sherbrooke J1K OA5, Québec, Canada

In this work, we have developed the growth of AlGaN/GaN high electron mobility transistor heterostructures on Silicon substrate for low cost power devices. We show the advantages of ammonia source MBE over the other growth techniques.

9:00-9:20

Tu-A2

Aluminum-free 450 nm nitride laser diodes grown by plasma assisted molecular beam epitaxy

G. Muziol(1), M. Siekacz(1)(2), H. Turski(1), S. Grzanka(1)(2), M. Krysko(1), J. Borysiuk(3)(4), P. Perlin(1)(2), C. Skierbiszewski(1)(2)

1 - Institute ofHighPressurePhysics,Sokolowska29/37,01-142Warsaw,Poland, 2 - Top GaN Ltd, Sokolowska 29/37, 01-142 Warsaw, Poland, 3 – Institute of Physics, Polish Academy of Sciences, Al. Lotnikow 32/46, 02-668 Warsaw, Poland, 4 - Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland

Aluminum-free laser diode (LD) operating at a wavelength of 450 nm grown by plasma assisted molecular beam epitaxy is demonstrated. In conventional nitride LD the AlGaN layers are used as claddings and as electron blocking layer (EBL). The new design without AlGaN layers consists of a separate confinement heterostructure with GaN claddings, $In_{0.08}Ga_{0.92}N$ waveguide and $In_{0.17}Ga_{0.83}N$ MQW region. The high In content $In_{0.08}Ga_{0.92}N$ waveguide provides sufficient optical confinement which allows to abandon the AlGaN cladding layers. Furthermore, a proper Mg doping profile allowed to exclude the AlGaN from EBL.

9:20-9:40

Tu-A3

Integration of 2-Dimensional Electron Gases and Microcavities Devices for Many-Body State Cavity Quantum Electrodynamics

S. Fält(1), S. Ravets(2), W. Wüster(1)(2), S. Smolka(2), F. Haupt(2), A. Imamoglu(2), W. Wegscheider(1)

1 - Solid State Physics Laboratory, Eidgenössische Technische Hochschule (ETH) Zurich, 8093 Zurich, Switzerland, 2 - Institute of Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Microcavities and 2-dimensional electron gases (2DEGs) can be monolithically combined. This allows excitations just above the 2DEG Fermi edge to couple strongly to the optical field of the cavity. By applying a magnetic field in this strong-coupling regime, quantum hall polariton excitations were observed. The growth of this AlGaAs-based device requires trade-offs to optimize the quality of both the microcavity and the 2DEG in the same growth. Additionally, tuning of the electron density and shifting the cavity resonance relative to the Fermi edge excitation are necessary tools for studying the underlying many-body physics.

Room B – Oxide and Hybrid Epitaxial Systems

8:30-8:50

Tu-B1

Oxygen Removal from $SrTiO_3$ (001) : Co_3O_4 and γ-Al_2O_3

K. Kormondy, A. B. Posadas, A. A. Demkov

Department of Physics, The University of Texas at Austin, Austin, Texas, 78712, USA

Here, we study the thermodynamics involved in formation of the oxygen vacancy-based two dimensional electron gas (2DEG) at the $SrTiO_3$ (STO) surface. MBE was employed to compare epitaxy of two spinel oxide overlayers, semiconductor Co_3O_4 and insulator Al_2O_3, on STO (001) substrates. In situ x-ray photoelectron spectroscopy was used to detect the presence of an oxygen-deficient layer in the Al_2O_3 /STO heterostructure. By comparing the two oxides, we illustrate the importance of enthalpy of formation in the oxide overlayer on the oxygen vacancy 2DEG in STO.

8:50-9:10

Tu-B2

Interface reactivity and epitaxial growth of $SrTiO_3$ and other functional oxides on Si and GaAs

B. Meunier(1), R. Moalla(1), A. Carretero-Genevrier(1), L. Largeau(2), J. Gazquez(3), P. Regreny(1), C. Botella(1), J. Penuelas(1), B. Vilquin(1), B. Wague(1), G. Grenet(1), G. Agnus(4), P. Lecoeur(4), M. G. Silly(5), F. Sirotti(5), R. Bachelet(1), G. Saint-Girons(1)

1 - Univ. de Lyon, INL-UMR5270/CNRS-ECL, 36 av. Guy de Collongue, 69134 Ecully cedex, France, 2 - LPN-UPR20/CNRS, route de Nozay, 91460 Marcoussis cedex, France, 3 - ICMAB-CSIC Barcelona, Campus UAB, E-08193 Bellaterra, Catalunya, Spain, 4 - Univ. Paris-Sud, Institut d'Electronique Fondamentale, Bât. 220, 91405 Orsay Cedex, France, 5 - Société Civile Synchrotron SOLEIL (ligne TEMPO), L'Orme des Merisiers, Saint-Aubin BP 48, F-91192 Gif-sur Yvette cedex, France

Functional oxides are key materials for further development of the micro-optoelectronic systems, providing that they can be integrated on semiconductor platforms. In the present contribution, we will present new insights on the chemical reactivity of epitaxial oxide/semiconductor heterointerfaces, provided by in-situ X-ray diffraction and photoemission experiments. We will also describe growth engineering strategies that allow for circumventing the limitations related to interface reactions, and show how such strategies allow for fabricating high quality oxide/semiconductor heterostructures with excellent functional properties.

9:10—9:40

Tu-B3

Routes to High-Mobility Oxide Films by MBE

S. Raghavan, T. Schumann, S. Stemmer

Materials Department, University of California, Santa Barbara, California, 93106-5050, USA

Single crystals of the wide band gap perovskite $BaSnO_3$ show high carrier mobility at room temperature. These properties makes $BaSnO_3$ a promising candidate for transparent conductors, power electronics, and as a channel material for integration with functional perovskite oxides. Growth of high quality thin films is critical for electronic devices. In this presentation, we discuss novel growth approaches for high quality epitaxial $BaSnO_3$ thin films using oxide molecular beam epitaxy (MBE). We show that a modified oxide MBE approach is needed for the growth of stoichiometric $BaSnO_3$. Thin film mobilities as high as 150 $cm^2V^{-1}s^{-1}$ at room temperature are demonstrated with this method.

Notes

8:30-8:50

Tu-C1

Phase Transitions, MBE and Spin-Splitting in the Multiferroic GeMnTe Rashba System

G. Springholz(1), J. Krempaský(2), D. Kriegner(3), S. Muff(2)(4), J. Minár(5), H. Volfová(5), J. Furthmüller(6), F. Bechstedt(6), H. Przybylinska(7), V. V. Volobuev(1), R. Kirchschlager(1), A. Ney(1), W. Jantsch(1), G. Bauer(1), V. Holy(3), H. Ebert(5), J. Braun(5), M. Fanciulli(2), N. Pilet(2), P. Warnicke(2), F. Bisti(2), V. Strocov(2), J. H. Dil(2)(4)

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Multiferroics combining ferroelectric and ferromagnetic order are of great interest due to their unique properties and potential device applications. In this work, we report on the MBE growth, structural, magnetic and electronic properties of multiferroic $Ge_{1-x}Mn_xTe$ films grown by MBE on BaF_2 (111) substrates and derive the corresponding multiferroic phase diagram as a function of composition. Using angle and spin-resolved photoemission spectroscopy, we show that ferroelectricity and ferromagnetism lead to a pronounced spin splitting of the electronic bands due to the Rashba-Zeeman effect. In addition, switching of the spin polarization by external magnetic fields is demonstrated.

8:50-9:10

Tu-C2

Interlayer exchange coupling in MBE grown GaMnAs-based multilayer systems

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Interlayer exchange coupling (IEC) in GaMnAs/GaAs:Be multilayer has been investigated by transport measurement. A few series of GaMnAs-based multilayer structures are prepared by varying carrier concentration in the structure and the thickness of spacer layer. The presence of antiferromagnetic (AFM) IEC in the structure was identified from the observation of the Giant magnetoresistance (GMR) – like behavior in the magnetoresistance measurement. While the Mn composition in the GaMnAs layer is not sensitive to the IEC of multilayer, the carrier concentration in the structure played a crucial role in determining IEC type of the GaMnAs-based multilayer systems.

9:10-9:30

Tu-C3

Epitaxial superconductor-semiconductor two-dimensional systems: platforms for quantum circuits

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In this work, we present recent progress in optimization of the growth of Al on InAs near surface quantum wells. We show the growth of InGaAs layers on top of InAs facilitates lower strain energy at the interface with Al and results in a flat and smooth growth allowing ultra-thin superconducting Al films. We further extend this work to growth of higher Tc superconductors (such as Nb) on these thin films Al and compare the results to direct growth of these superconductors.

9:30-9:50

Tu-C4

High-Temperature Ferromagnetism in Heavily Fe-doped Ferromagnetic Semiconductor (Ga,Fe)Sb

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We show high-temperature ferromagnetism in heavily Fe-doped ferromagnetic semiconductor $(Ga_{1-x},Fe_x)Sb$ (x = 17-25%) thin films grown by low-temperature molecular beam epitaxy (LT-MBE). Our crystal structure analysis by scanning transmission electron microscopy (STEM) indicates that the $(Ga_{1-x},Fe_x)Sb$ thin films maintain the zinc-blende crystal structure up to x = 25%. The intrinsic ferromagnetism was confirmed by magnetic circular dichroism (MCD) spectroscopy and anomalous Hall effect (AHE) measurements. The Curie temperature reaches 340 K for x = 25%, which is the highest value reported so far in intrinsic III-V ferromagnetic semiconductors.

Room A – MBE grown Devices

Tu-A4

High yield, low density InAs/GaAs quantum dots as quantum light sources for 900- 1300 nm operation

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Strategies for growth of low density InAs/GaAs quantum dots (QDs) are presented, giving single dot emission with a linewidth of 2 μeV at 4 K. Variation of growth conditions during capping, either by In- flush or InGaAs capping, gives wavelength control from 900 to >1300 nm range. The QDs are incorporated into waveguides and on-chip photon antibunching, resonance fluorescence and unidirectional spin transfer are demonstrated. QDs emitting at 1300 nm have a fine structure splitting as low as ~20 μeV, and are strain tunable over a range up to 46 μeV, which is promising for a telecoms-wavelength entangled photon source.

9:40-10:00

Tu-A5

Tailoring second-order harmonic generation with crystal antiphase domains in GaP/Si

P. Guillemé(1), C. Cornet(1), M. Vallet(2), M. Bahri(3), L. Largeau(3), G. Patriarche(3), A. Létoublon(1), J. Stodolna(2), Y. Dumeige(1), J. Le Pouliquen(1), P. Féron(1), A. Ponchet(2), O. Durand(1) and Y. Léger(1)

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GaP is a promising candidate for the development of integrated photonic functions on silicon, because of its quasi lattice-matching with Si and its interesting χ(2) non-linear properties. We present the realization of GaP-based microdisks on Si substrates, and discuss their optical properties, especially the antiphase domains (APDs) impact on second-order harmonic generation. We show that the relevant parameter is the average polarity of the crystal while the size of the APDs does not impact the non-linear processes. The control of the APD annihilation with AlGaP markers is found to be a promising route towards nonlinearity engineering in Si-integrated photonic devices.

10:00-10:20

Room B – Oxide and Hybrid Epitaxial Systems

Tu-B4

GaAs Core / $SrTiO_3$ Shell Nanowires Grown by Molecular Beam Epitaxy

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We have studied the growth of a $SrTiO_3$ shell on self-catalyzed GaAs nanowires grown by vapor-liquid-solid assisted molecular beam epitaxy on Si(111) substrates. To control the growth of the $SrTiO_3$ shell, the GaAs nanowires were protected using an arsenic capping/decapping procedure in order to prevent uncontrolled oxidation and/or contamination of the nanowire facets. Reflection high energy electron diffraction, scanning electron microscopy, transmission electron microscopy and x-ray photoelectron spectroscopy were performed to determine the structural, chemical and morphological properties of the heterostructured nanowires.

9:40-10:00

Tu-B5

Formation of nanoscale $BaTiO_3$ MOSCAPS on Germanium without wet-etching

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Difficulties of chemically etching titanates hinders their commercial use in device manufacturing. Here, we report the selective area *in finestra* growth of highly crystalline $BaTiO_3$ within photolithographically defined openings of a sacrificial SiO_2 layer on a Ge (001) wafer by molecular beam epitaxy. After the $BaTiO_3$ deposition, the sacrificial SiO_2 can be etched away, revealing isolated nanoscale gate stacks circumventing the need to etch the titanate thin film. The crystallinity of the samples is confirmed using RHEED, XRD and TEM. Electrical measurements are carried out on the newly formed MOSCAPS.

10:00-10:20

10:20-10:50

Coffee break
10:20 – 10:50

Coffee break
10:20 – 10:50

10:20-10:50

Room A – MBE grown Devices: Solar cells

Tu-A6

Radial Direct Bandgap p-i-n GaNP Microwire Solar Cells with Enhanced Short Circuit Current

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We show dilute nitride heterostructure core/shell microwire solar cells utilizing the combination of reactive-ion etching to create the cores (GaP) and molecular beam epitaxy to create the shells (GaNP). Systematic studies of cell performance over a series of microwire lengths, array periods, and microwire sidewall morphologies were conducted to shed light on performance-limiting factors and to optimize the cell efficiency. Compared to thin film solar cells in the same growth run, the microwire solar cells exhibit greater short circuit current but poorer open circuit voltage due to greater light absorption and number of defects in the microwire structure, respectively.

10:50-11:10

Room B – III-V compounds

Tu-B6

Quantum Heterostructures Based on GaAs Nanomembranes

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Vertically-grown nanomembranes were obtained using catalyst-free MBE growth on GaAs (111)B. The membranes were characterized by TEM and shown to be almost entirely twin-free while surprisingly exhibiting a single high-energy {221} facet. AlGaAs/GaAs quantum well heterostructures were then also grown and characterized by cathodoluminesence spectroscopy. The quantum well emission energy depended on the facet orientation with respect to the molecular beams. Additionally, localized emission could also be observed at distinct points along the membrane. This quantum-dot-like emission is attributed to Al aggregation at the facet edges, as has been observed in AlGaAs nanowire shells.

10:50-11:10

Room C – Spintronics and Topological Materials

Notes

9:50-10:20

Tu-C5

MBE-grown thin films of topological insulators and their quantized Hall effects

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Topological insulators (TIs) are a new class of semiconductors displaying charge-gapped insulating behavior in the bulk but hosting a spin-polarized massless Dirac electron state at the surface. Quantum transport in Dirac electron systems such as half integer quantum Hall effect (QHE) and quantum anomalous Hall effect (QAHE) has recently been attracting much attention by breaking time reversal symmetry. These quantized phenomena in 3D-TIs have been extensively studied in Bi-based chalcogenides such as Bi_2Se_3, Bi_2Te_3, Sb_2Te_3 and their combined/mixed compounds in both bulk and thin films form. Here, we report the thin film growth of carrier tuned topological insulator $(Bi_{1-x}Sb_x)_2Te_3$ and realization of the QHE and QAHE on the surface Dirac states in $(Bi_{1-x}Sb_x)_2Te_3$ films, its Cr-doped compound $Cr_x(Bi_{1-y}Sb_y)_{2-x}Te_3$ and their multilayer structures. These quantizations of Hall conductivity can be understood by the physical picture of two surface states at top and bottom of a TI thin film. These observations of the quantization of Hall effects in 3D TI films may pave a way toward TI-based electronics.

10:20–10:50

Coffee break
10:20 – 10:50

Room C – Wide Bandgap semiconductors: Doping

Notes

10:50-11:10

Tu-C6

Electrical Properties of GaN:Mg Layers with High Acceptor Concentrations

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Heavily Mg-doped GaN was grown by ammonia molecular-beam epitaxy. Low growth temperature of 740 °C decreases the incorporation of donor-like defects, which is responsible for *p*-type doping compensation, to less than 3×10^{17} cm^{-3}. A net acceptor concentration of 7×10^{19} cm^{-3} with a corresponding hole concentration as high as 2×10^{19} cm^{-3} was achieved at room temperature. Using such a high Mg doping level, we achieved ohmic characteristics. For a Mg concentration of 5×10^{19} cm^{-3}, the contact resistance reached a minimum value of 2×10^{-5} Ωcm^2.

	Room A – MBE grown Devices: Solar cells	Room B – III-V compounds	
11:10-11:30	**Tu-A7** **Combined MBE-MOCVD process for high-efficiency multijunction solar cells** A. Tukiainen(1), A. Aho(1), G. Gori(2), V. Polojärvi(1), M. Casale(2), E. Greco(2), R. Isoaho(1), T. Aho(1), M. Raappana(1), R. Campesato(2), M. Guina(1) *1 – Tampere University of Technology, Optoelectronics Research Centre, PO Box 692, FI-33101, Tampere, Finland, 2 – CESI S.p.A., Via Rubattino 54, 20134 Milan, Italy* We present a fabrication method for high-efficiency GaInP/GaAs/GaInNAs triple junction solar cells, employing molecular beam epitaxy (MBE) and metal-organic chemical vapor deposition (MOCVD) processes. The method combines the advantages of both epitaxial techniques, the high quality of MBE grown dilute nitrides and fast growth rate offered by MOCVD for standard III-V compounds. The GaInNAs bottom junction is first grown by MBE and then the rest of the structure is deposited by MOCVD. Triple junction cells with conversion efficiency of ~29% at AM0 are demonstrated, opening a new perspective on cost-effective fabrication of high-efficiency multi junction solar cells for space and concentrated photovoltaic applications	**Tu-B7** **Selective area MBE growth of InGaAs on InP for MOSFET applications** L. Desplanque, M. Pastorek, A.-B. Fadjié, N. Wichmann, S. Bollaert and X. Wallart *Institute of Electronics, Microelectronics and Nanotechnology, CNRS and University of Lille, Avenue Poincaré, CS 60069, 59652 Villeneuve d'Ascq Cedex, France* This work deals with the selective area molecular beam epitaxial growth of InGaAs on InP for MOSFET applications. We show how the use of an atomic hydrogen flux during the growth promotes the growth selectivity of InGaAs with respect to a SiO_2 mask. This growth mode is used for the formation of raised heavily doped source/drain contacts for the fabrication of InAs based MOSFET as well as for the production of InGaAs in-plane nanowire arrays.	11:10-11:30
11:30-11:50	**Tu-A8** **Enhancement of open circuit voltage in InGaAsP inverted thin film solar cells grown by solid-source molecular beam epitaxy** R. Oshima, K. Makita, T. Tayagaki, T. Sugaya *National Institute of Advanced Industrial Science and Technology, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan* We fabricated InGaAsP inverted thin film solar cells grown with 1.05 eV bandgap by solid-source molecular beam epitaxy, which are possible candidates for InP-based bottom cells in mechanically stacked multi-junction cells. The inverted cells with a highly reflective mirror on the backside, which may enhance photon recycling, were processed on Si supporting substrates. The solar cell's open circuit voltage (V_{OC}) was evaluated using the W_{OC} (= Eg/q - V_{OC}) parameter. The Improved W_{OC} value of 0.463 V was obtained for the inverted cell, in comparison with that of 0.486 V for the upright cell processed on InP substrates.	**Tu-B8** **Femtosecond Laser Modification of MBE-Grown III-V Nanostructures on Silicon** S. R. Zandbergen, R. Gibson, P. Keiffer, B. Amirsolaimani, S. Mehravar, K. Kieu, G. Khitrova *College of Optical Sciences, University of Arizona, 1630 E University Blvd., USA* A unique nanostructure of indium, gallium, and arsenic was grown via molecular beam epitaxy (MBE) on an n-doped silicon (100) substrate. It was observed under femtosecond (fs) laser exposure that the second and third harmonic generation signals (SHG and THG) from the nanostructure increased with the exposure time. This interaction physically altered the structures on the surface. The effect was highly polarization dependent, resulting in wire-like structures from linear polarization and donut- and pancake like structures from circular polarization.	11:30-11:50
11:50-12:10	**Tu-A9** **Si-doped InAs/GaAs quantum dot solar cell with AlAs cap layers** Dongyoung Kim(1), Mingchu Tang(1), Jiang Wu(1), Sabina Hatch(1), Yurii Maidaniuk(2), Vitaliy Dorogan(2), Yuriy I. Mazur(2), Gregory J. Salamo(2), Huiyun Liu(1) *1 – Department of Electronic and Electrical Engineering, University College London, Torrington Place, London WC1E 7JE, UK. 2 – Institute for Nanoscience and Engineering, University of Arkansas, Fayetteville, Arkansas 72701, USA* In this work, the effect of Si doping on InAs/GaAs quantum dot solar cells with AlAs cap layers is studied. The AlAs cap layers suppress the formation of the wetting layer during quantum dot growth. This helps achieve quantum dot state filling, which is one of the requirements for strong sub-bandgap photon absorption in the quantum dot intermediate band solar cell, at lower Si doping density. Furthermore, the passivation of defect states in the quantum dots with moderate Si doping is demonstrated, which leads to an enhancement of the carrier lifetime in the quantum dots, and hence the open-circuit voltage.	**Tu-B9** **Correlating structure and optical properties of self-catalyzed GaAs nanowires grown on lithography-free Si/SiO_x patterns** E. Koivusalo, T. Hakkarainen and M. Guina *Optoelectronics Research Centre, Tampere University of Technology, P.O. Box 692, FIN-33101 Tampere, Finland* We present an analysis of self-catalyzed GaAs nanowires (NWs) grown on lithography-free Si/SiO_x patterns using molecular beam epitaxy. In particular we report a correlation of structural and optical properties using high-resolution x-ray diffraction (HR-XRD) and photoluminescence (PL). Our self-catalyzed method is shown to produce high quality NWs with high phase purity. Based on HR-XRD analysis, the stems of the NWs have zinc blende (ZB) structure, whereas crystallizing the catalyst droplets is found to form wurtzite (WZ) segments to the NW tips. This is further confirmed by photoluminescence study whereas low energy shoulder in the PL emission of the NWs with crystallized catalyst droplets is observed.	11:50-12:10
12:20-13:40	Lunch 12:20 - 13:40	Lunch 12:20 - 13:40	12:20-13:40

Room C – Wide Bandgap semiconductors: Doping

Notes

11:10-11:30

Tu-C7

Highly Degenerate p-type GaN and AlGaN Grown via Metal Modulated Epitaxy

E. A. Clinton(1), B. P. Gunning(1), C. M Fabien(1), J. J. Merola(1), W. A. Doolittle(1), S. Wang(2), A. M. Fischer(2), F. A. Ponce(2)

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Mg-doped, p-type GaN films grown via metal modulated epitaxy exhibit both bulk and two-dimensional electrical transport when grown on AlN buffer layers. Three conduction mechanisms are analyzed via temperature dependent Hall measurements: valence band conduction, impurity band conduction, and 2D conduction at the GaN/AlN interface. Hole concentrations exceed $2x10^{19}$ cm^{-3} for GaN and AlGaN films up to 27% Al and exhibit an activation energy of 51 meV for GaN. Electroluminescence confirmed hole injection in a multi-quantum well light-emitting diode and a p-i-n diode. Hole degeneracy is proven via demonstration of strong light emission when submerged in liquid nitrogen at 77K.

11:30-11:50

Tu-C8

Incorporation of Silicon in Al-rich $Al_xGa_{1-x}N$ (x>0.7) by MBE

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Silicon n-type doping of Al-rich AlGaN alloys is needed for deep ultra-violet photonic devices. We report the incorporation of high concentration (~$5x10^{19}$ cm^{-3}) of silicon in Al-rich AlGaN by plasma assisted molecular beam epitaxy. Secondary ion mass spectroscopy quantified the correlation of Si doping with the Al composition in AlGaN. Hall-effect measurements of Si-doped $Al_{0.7}Ga_{0.3}N$ layers showed high electron concentrations of ~$1.5x10^{19}$ cm^{-3} with an electron mobility of ~10 $cm^2V^{-1}s^{-1}$ at 300 K. Combining SIMs chemical profiling with temperature-dependent electron transport studies highlight the n-type conductivities achievable in high Al-composition AlGaN as the electron injection layers in deep-UV LEDs and Lasers.

11:50-12:10

Tu-C9

Unintentional Boron Incorporation in AlGaN Layers Grown by Plasma-assisted MBE Using Highly Efficient RF Plasma-sources

S.V. Novikov, C.T. Foxon

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Plasma-assisted molecular beam epitaxy (PA-MBE) is now widely used for the growth of group III-nitrides. Many years ago it became clear that during PA-MBE there is unintentional doping of GaN with boron (B) due to decomposition of the pyrolytic boron nitride (PBN) cavity of the RF plasma source. In our presentation we will discuss the unintentional B incorporation for PA-MBE growth of $Al_xGa_{1-x}N$ using highly efficient RF plasma sources.We have studied a wide range of MBE growth conditions with $Al_xGa_{1-x}N$ growth rates from 0.2 to 3μm/h, RF powers from 200 to 500W and growth times up to several days.

12:20-13:40

Lunch

12:20 - 13:40

Room A – Group-IV semiconductors

13:40-14:10

Tu-A10

Strained-Engineered Group IV Semiconductors

Oussama Moutanabbir

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Strain engineering is ubiquitous in design and fabrication of innovative, high-performance electronic, optoelectronic, and photovoltaic devices. The increasing importance of strain-engineered epitaxial nanoscale materials has raised significant challenges at both growth and characterization levels. With this perspective, this paper will cover key advances in growth of strained silicon-compatible group IV films and nanostructures with focus on strained silicon, strained germanium, ultrathin strained silicon-on-insulator, and strained nanowires. The paper will also address key characterization techniques utilized to elucidate the influence of strain on the basic properties of these material systems.

14:10-14:30

Tu-A11

Continuum modeling of Ge/Si heteroepitaxy in the presence of misfit dislocations

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The interplay between elastic and plastic relaxation during the growth of heteroepitaxial systems is investigated. A continuum model for the growth dynamics, including both deposition and surface diffusion, is developed and applied to Ge/Si(001). The material transfers are defined according to the tendency toward free energy minimization, as given by the balance between surface energy, including substrate wetting contributions, and strain relaxation. Dislocations are introduced in the growing film based on an energetic criterion. The predicted evolution is in agreement with experimental data. A cyclic growth process, observed in the literature, is reproduced by the simulations.

14:30-14:50

Tu-A12

Low-temperature epitaxial growth of $Mn_5Ge_3C_x$ films and δ-doped Ge layers for electrical spin injection

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Reactive deposition epitaxy (RDE) at room temperature was used to form $Mn_5Ge_3C_x$ on Ge(111) substrate. $Mn_5Ge_3C_x$, a ferromagnetic compound is commonly grown by solid phase epitaxy (SPE) which entail some issues on the interface quality because of the involved annealing. The interfaces and films obtained by this RDE growth process are characterized on a structural, magnetic and electrical levels to demonstrate the potentiality of the $Mn_5Ge_3C_x$ on Ge(111) for spin injection.

Room B – III-V compounds

13:40-14:00

Tu-B10

Growth of $Al_xIn_{1-x}As_ySb_{1-y}$ for InAs-based THz Quantum Cascade Lasers

A.M. Andrews(1), T. Zederbauer(1), D. MacFarland(1), H. Detz(2), W. Schrenk(1), M. Brandstetter(3), M.A. Kainz(3), M. Krall(3), S. Schönhuber(3), K. Unterrainer(3), and G. Strasser(1)

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The growth of $Al_xIn_{1-x}As_{1-y}Sb_y$ molecular beam epitaxy is studies with the goal of lattice matching to InAs for the development of MIR and THz intersubband optoelectronics. $Al_{0.46}In_{0.54}As_ySb_{1-y}$, located in the center of the miscibility gap, was grown with varying substrate temperatures and group V flux. High quality lattice-matched layers were only possible <450 °C. Using these growth conditions, the first InAs-based THz quantum cascade laser was grown. The 3.8 THz three-well active region lases in a magnetic field >4.3 T at 4.2 K.

14:00-14:20

Tu-B11

InSb/InAs/InGa(Al)As/GaAs(001) Metamorphic Nanoheterostructures Grown by MBE and Emitting Beyond 3 µm

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We report on MBE growth and properties of InAs/$In_{0.75}Ga_{0.25}As$/$In_{0.75}Al_{0.25}As$ metamorphic quantum wells (QWs) with ultrathin InSb insertions, grown on GaAs (001). InAlAs metamorphic buffer layers with linear and convex profiles are used to match gradually the lattice parameter from GaAs to that of InGa(Al)As barriers. The single type-II InSb insertion in the InAs QW shifts the photoluminescence (PL) peak maximum from below to above 3 µm due to recombination of holes localized in InSb with electrons accumulated in the InAs QW. The mid-infrared PL in the structures with and without InSb insertion survives up to 260 and 300K, respectively.

14:20-14:50

Tu-B12

Antimonide/Arsenide Heterostructures for Electronic and Electro-Optic Devices

Brian R. Bennett, Chadwick L. Canedy, and J. Brad Boos

Naval Research Laboratory, Washington, DC USA

Over the last two decades, significant progress has been made in the growth of antimonide/arsenide heterostructures by molecular beam epitaxy. This talk will review the work at the U.S. Naval Research Laboratory and collaborators on Sb/As materials for electronic and electro-optic devices. Transistors and circuits operate at high speeds with extremely low power consumption. Infrared interband cascade lasers demonstrate CW operation above 100°C, low pulsed threshold current densities, and low drive power.

Room C – II-VI compounds

Notes

13:40-14:00

Tu-C10

Non polar ZnO/(Zn,Mg)O homoepitaxial heterostructures for intersubband devices

M. Hugues(1), N. Le Biavan(1,2), D. Lefebvre(1), L. Wang(3), G. Brémond(3) , V. Sallet(4), F. Jomard(4), G. Patriarche(5), M. Montes Bajo(6), J. Tamayo-Arriola(6), A. Hierro(6), P. Quach(7), A. Jollivet(7), M. Tchernycheva(7), F.H. Julien(7), J. M. Chauveau(1)(2)

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The development of Zinc Oxide (ZnO)-based applications have been strongly limited due to the lack of reproducible *p*-type doping. Here we present novel opportunities in the field of unipolar oxide semiconductors offered by the improvements of the MBE technique. We demonstrate that the structural and optical properties of nonpolar ZnO/ZnMgO multiple quantum wells exhibit the level required for intersubband devices in terms of defects, surface and interface roughness and doping. At a first step, intersubband transitions have been observed from such structures.

14:00-14:20

Tu-C11

Microdisks coupled with Waveguides of II/VI quantum well heterostructures

G. Schmidt, T. Rieger and A. Pawlis

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Waveguides and microdisks of molecular beam epitaxy grown CdSe/ZnSe/(Zn,Mg)Se quantum well structures on (In,Ga)As quasi-substrates provide suitable components of integrated-optical devices within the whole visible spectrum of light emission. Here we present an integrated-optical device composed of a microdisk with an adjacent waveguide membrane and outcoupling gratings fabricated by electron beam lithography and a combination of advanced wet-etching techniques.Analysis of the waveguiding properties via spatial-resolved µ-photoluminescence spectroscopy demonstrates efficient photon overcoupling from the microdisk to the waveguide.

14:20-14:40

Tu-C12

$Mg_{0.13}Cd_{0.87}Te/Mg_yCd_{1-y}Te$ (y>0.13) Double Heterostructures and Photovoltaic Devices for High-Efficiency II-VI/Si Tandem Cells

Calli M. Campbell(1)(2), Xin-Hao Zhao(1)(2), Ernesto Suarez(1)(3), Jacob Becker(1)(3), Yuan Zhao(1)(3), Mathieu Boccard(3), Maxwell B. Lassise(1)(3), Zachary Holman(3), and Yong-Hang Zhang(1)(3)

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$Mg_{0.13}Cd_{0.87}Te$ (1.7 eV)/Si (1.1 eV) tandem cells have the potential to reach a conversion efficiency greater than 40% at low cost. Un-doped and n-type doped $Mg_{0.13}Cd_{0.87}Te/Mg_yCd_{1-y}Te$ (y>0.13) double heterostructures (DHs) grown by MBE feature a 1.7 eV bandgap and exhibit long carrier lifetimes up to 96 ns. Devices consisting of an n-type $CdTe/Mg_xCd_{1-x}Te$ or $Mg_{0.13}Cd_{0.87}Te/Mg_yCd_{1-y}Te$ DH absorber, a p-type amorphous hydrogenated silicon (a-Si:H) hole contact layer and an ITO top electrode are demonstrated with very high Voc and efficiency, 1.096 V and 17%, and 0.963 V and 4.63%, respectively.

14:40-15:00

Tu-C13

CdTe layer structures for X-ray and gamma-ray detection directly grown on the Medipix readout-chip by MBE

A.Vogt, S. Schütt, K. Frei, M.Fiederle

Materials Research Center, University of Freiburg, Stefan-Meier-Str. 21, 79104 Freiburg, Germany

This work investigates the potential of CdTe semiconducting layers directly deposited on the readout-chip by a MBE used for radiation detection. Due to the high Z number of CdTe and the low electron hole pair creation energy a thin layer suffice for satisfying photon absorption. The deposition takes place in a modified MBE system enabling growth rates up to 10 µm/h while the UHV conditions allow the required high purity for detector applications. Additionally, the deposition of a back contact layer sequence in one process simplifies the complex production of an efficient contact on CdTe with aligned work functions.

Room A – Group-IV semiconductors

14:50-15:10

Tu-A13

SiGe alloy nanowires grown by molecular beam epitaxy: a μ-Raman study

M. I. Alonso(1), A. Ruiz(2), M. Alonso(2), E. Bailo(3) P. O.Vaccaro (1)(4), A. R. Goni (1)(4), and M. Garriga (1)

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We study the growth of in-plane SiGe alloy nanowires by molecular beam epitaxy on Si substrates using the vapor-liquid-solid mechanism. These in-plane nanowires grow from liquid AuSi droplet seeds which are obtained by annealing Au layers deposited on clean Si(001) surfaces. By continuously supplying Ge to the liquid droplets, an epitaxial process takes place, where wires crawl along <110> directions of the Si substrate, giving rise to the reproducible achievement of self-assembled in-plane SiGe nanowires. The morphology of the obtained nanostructures is characterized by scanning electronic and atomic force microscopies, and their composition and strain status is evaluated by micro-Raman imaging.

15:10-15:30

Tu-A14

Au droplet motion and Si nanowire growth as a result of Au deposition on different Si substrates

S. Curiotto, F. Leroy, F. Cheynis, P. Muller

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Au deposition on Si substrates of different orientations, above the Au-Si eutectic temperature, gives origin to a variety of interesting phenomena. These range from theformation and motion of Au dropletsto the growth ofSi nanowires. We study in-situ and in-real-time these phenomena by low energy electron microscopy (LEEM). The dissolution of Si in Au is the cause of the observed mechanisms. The details depend on the anisotropy of dissolution of the Si substrates: the {111} Si planes dissolve slower than other orientations and therefore they define the limits of the droplet shape and motion.

15:30-16:00

Coffee break
15:30 – 16:00

16:00-18:00

Poster session
16:00 – 18:00

Room B – III-V compounds

14:50-15:10

Tu-B13

MBE of strained-layer InAs/GaInSb superlattices for long-wavelength photodetectors

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We report on characterization of strained-layer InAs/$Ga_{1-x}In_xSb$ superlattices with alloy composition x<0.4 for long-wavelength photodetectors. The thickness and composition of the layers were chosen to obtain a narrow SL energy gaps <50meV for optical absorption in terahertz spectral range. The structures were grown on GaSb (100) substrates by solid source MBE. Structural and surface quality was analyzed using X-ray diffraction, AFM, STEM/EDX and RBS. Transmittance and reflectance spectra were measured for evaluation of optical properties. Results of the characterization demonstrate feasibility of the pseudomorphic growth of strained InAs/GaInSb SLs for long-wavelength photodetectors with good optical properties.

15:10-15:30

Tu-B14

MBE growth of periodically-oriented GaSb on GaAs templates for frequency conversion in the mid-infrared wavelength range.

L. Cerutti(1)(2), S. Roux(3), G. Patriarche(4), M. Garcia(5), B. Gérard(5), A. Grisard(3) and E. Tournié(1)(2)

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We report on the growth, structural characterizations, processing and optical measurement of structures for the realization of low-loss III-Sb waveguides on periodically-patterned GaAs templates. We demonstrate that, in spite of the large lattice-mismatch of 8%, the metamorphic growth of III-Sb on GaAs allows preserving the polarity periodicity and a high crystalline quality. Optical losses as low as 1 – 3 dB/cm are achieved near 2 μm.

15:30-16:00

Coffee break
15:30 – 16:00

16:00-18:00

Poster session
16:00 – 18:00

	Room C – II-VI compounds	Notes
15:00-15:30	**Tu-C14** **Quantum-Well Infrared Photodetectors from Wide Band Gap II-VI Semiconductors** A. Shen *Department of Electrical Engineering, City College of New York, New York, NY 10031, USA* We report the realization of quantum-well infrared photodetectors (QWIPs) from wide band gap II-VI semiconductors. QWIPs working in both long-wave infrared (LWIR) and mid-wave infrared (MWIR) spectral regions have been designed, grown, fabricated and characterized. Multi-lead two-color QWIPs that can operate either individually or simultaneously in the two spectral regions have also been demonstrated.	
15:30-16:00	Coffee break 15:30 – 16:00	
16:00-18:00	Poster session 16:00 – 18:00	

Room A – 2D materials (graphene, MoS_2, WS_2,...)

8:30-9:00

We-A1

Tackling MBE challenges through experiment and theory: nanostructures, spintronics and 2D materials

Gavin R. Bell(1), David Quigley(1), Peter Brommer(1), Gwilym P. Enstone(1), Paul A. Mulheran(2)

1 - University of Warwick, Coventry, CV4 7AL, UK, 2 - Strathclyde University, Glasgow, G1 1XJ, UK

Kinetic Monte Carlo (KMC), molecular dynamics (MD) and related simulation methods have provided insight into epitaxial growth phenomena for several decades, helping to bridge the huge range of time and length scales relevant to epitaxial growth. The talk will cover recent applications of KMC and MD methods to understanding the growth of graphene on copper and the growth of metal nanoclusters on chemically modified graphene. Even in the absence of strong substrate-overlayer interaction, as for van der Waals or 2D materials, epitaxial orientation can occur. In the case of graphene on copper it is also important to explain how ordered, oriented graphene grows on a nearly molten surface.

9:00-9:20

We-A2

MBE Growth of Large-Area Hexagonal Boron Nitride/Graphene Heterostructures on Ni/MgO(111) Substrates

J. Marcelo J. Lopes, Siamak Nakhaie, Joseph M. Wofford, Manfred Ramsteiner, Thilo Krause, Michael Hanke, Henning Riechert

Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

Vertical heterostructures consisting of hexagonal boron nitride (h-BN) and graphene are very promising for many applications. However, it is still difficult to achieve large-area synthesis for this material system. Here we report on a MBE-based growth method for the production of h-BN/graphene heterostacks on Ni(111)/MgO(111) templates. AFM reveals that large-area, continuous heterostructure films are formed over the Ni surface. Raman spectroscopy confirms these results and also shows that our procedure results in high-crystalline quality for both materials. Synchrotron-based grazing incidence diffraction is used to demonstrate that the top h-BN layer is unstrained, while the graphene has its lattice under strong compression.

9:20-9:40

We-A3

Solid and gas source MBE of graphene on Ge(001)

G. Lippert(1), J. Dabrowski(1), J. Avila(2), J. Baringhaus(3), I. Colambo(4), Yu. S. Dedkov(1), F.Herziger(5), G.Lupina(1), J. Maultzsch(5), T. Schaffus(1), T. Schroeder(1,6), M. Sowinska(1)(6), Ch.Tegenkamp(3), D. Vignaud(4), M.-C. Asensio(2)

1 - IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany, 2 - Synchrotron SOLEIL, Saint Aubin, BP 48, 91192 Gif-sur-Yvette, France, 3 - Institut für Festkörperphysik, Leibniz Universität, Appelstr. 2, D-30167 Hannover, Germany, 4 - I.E.M.N. - Epitaxie, Av. Poincaré BP 60069, 59652 Villeneuve d'AscqCedex, France, 5 - Institut für Festkörperphysik, TU Berlin, Hardenbergstr.36, 10623 Berlin, Germany, 6- BTU Cottbus-Senftenberg, Konrad Zuse Str. 1, 03046 Cottbus, Germany

A severe obstacle to use graphene in microelectronic and optoelectronic technology is that the available methods to grow graphene are not easy to integrate into a reliable and profitable circuit production process. Growth of graphene on germanium substrates could bypass at least some of these problems. Here we report physical properties, surface reaction and diffusion for graphene films grown on Ge(001) from ethene (C_2H_4) and the graphite from solid source, and their relevance for the observed behavior. The determination of the properties was done by Raman spectroscopy, angle-resolved photoemission spectroscopy (ARPES), and ab initio density functional theory (DFT) calculations.

Room B – Oxide and Hybrid Epitaxial Systems

8:30-8:50

We-B1

Record Electrical Conductivity and Opto-Ionic Multifunctional Coupling in MBE Grown p-type Oxides

J. Shank, M. B. Tellekamp, W. A. Doolittle

Georgia Institute of Technology, 777 Atlantic Dr., Atlanta, GA, 30332, USA

Lithium niobite (Li_xNbO_2) is a mixed ion-electron conductor exhibiting multi-functional properties. The lithium content can be modulated by electrical, optical, and chemical means changing the electrical resistivity, optical band structure, and electrochemical potential. Halide-MBE produces the highest crystal quality Li_xNbO_2 thin films, but leaves the material lithium deficient. The MBE crystal quality and high lithium deficiency combine to produce record p-type oxide conductivity, but multi-functional behavior is dampened at low lithium content. Optical modulation of the conductivity (opposite that of photoconductivity) via opto-ionic coupling was observed. Effects of chemically varied lithium content post-growth on the multi-functional performance will be presented.

8:50-9:10

We-B2

Radical MBE Approaches for Perovskite Oxides with Elements of Low Oxidation Potentials

Abhinav Prakash and Bharat Jalan

Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, MN 55455, U.S.A.

We will present our recent development of the radical MBE approach, which utilizes the highly reactive metal radicals to not only overcome the oxidation challenges in oxide MBE but also provides potential routes to grow metal oxides of elements possessing low oxidation potentials (such as V, Sn, Ni, Ir, W, etc) or in other words, elements, which are hard to oxidize under standard MBE growth conditions. Detailed study of MBE growth of $BaSnO_3$, doping and electronic transport properties and their relationships with structural defects will be presented.

9:10-9:40

We-B3

Wacky Oxides: Rich Properties in Search of Devices

D.G. Schlom(1)(2)

1- Department of Material Science and Engineering, Cornell University, Ithaca, New York 14853, USA, 2 - Kavli Institute at Cornell for Nanoscale Science, Ithaca, New York 14853, USA

With the goal of helping to get out the word about the novel properties of oxides to the people with an interest in exploiting their unusual properties to make devices, this talk will provide specific examples of the treasure-trove of unparalleled properties exhibited by oxides. It will also briefly discuss how such wacky oxides can be epitaxially integrated with mainstream semiconductors.

Room C – Nanostructures: Nanowires	Notes

8:30-8:50

We-C1

Twin-Free InAs(Sb) Nanowires for Quantum Transport Experiments

H. Potts(1), M. Friedl(1), G. Tütüncüoglu,(1), K. Tang(2), F. Matteini,(1), P. C. McIntyre(2), A. Fontcuberta i Morral(1)

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We study the growth of catalyst-free InAs(Sb) nanowires and investigate their crystal structure and electronic properties. Wurtzite stacking is suppressed upon incorporation of antimony and twin-free nanowires can be obtained by increasing the antimony content above 25%. Field-effect transistor devices are fabricated by e-beam lithography to measure the electronic properties of the wires. In order to get more reproducible results we passivate the surface of the wire with a high-quality Al_2O_3 shell. The alumina layer not only helps to passivate the surface, it also allows us to make top-gated devices. Finally, we also study congruent evaporation and demonstrate the fabrication of nanowires with diameters below 20nm which can be used for quantum transport experiments.

8:50-9:10

We-C2

InAs/InP quantum dot nanowires with abrupt interfaces grown by MBE on silicon

A. Mavel(1a,b), P. Regreny (1b), G. Patriarche(2), B. Masenelli(1a), N. Chauvin(1a), M. Gendry(1b)

1 - Université de Lyon, Institut des Nanotechnologies de Lyon (INL)-UMR 5270-CNRS, a - INSA Lyon, 7 avenue Capelle, F-69621 Villeurbanne, France, b - Ecole Centrale de Lyon, 36 rue Guy de Collongue, F-69134 Ecully, France, 2 - Laboratoire de Photonique et de Nanostructures (LPN), CNRS, Université Paris-Saclay, route de Nozay, F-91460 Marcoussis, France

The structural and optical properties of InAs/InP quantum dot nanowires (QD-NWs) grown on Si(111) by molecular beam epitaxy using the vapor-liquid-solid method with gold-indium droplets as catalyst are investigated as a function of the growth parameters. When the temperature of formation of the catalyst droplets is lower than 550°C, almost only vertically standing pure wurtzite InP NWs are grown on Si(111). Then, it is shown than an InP pyramid-like pedestal is formed prior to the NW growth. A precise control of the III and V flux for the growth of InAs insertions allows to grow InAs QDs with atomically sharp interfaces.

9:10-9:30

We-C3

Droplet-confined alternate pulsed epitaxy of GaAs nanowires on Si substrates: meeting the typical MBE standards

T. Tauchnitz(1)(2), L. Balaghi(1)(2), L. Bischoff(1), R. Hübner(1), H. Schneider(1), M. Helm(1,2), E. Dimakis(1)

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We introduce a growth scheme with alternate Ga and As_4 pulses for the self-catalyzed growth of free-standing GaAs nanowires on Si(111) substrates. Unlike the conventional growth mode, our scheme offers a wide growth temperature window (450 – 600 °C), low growth rates (down to 1-2 monolayers per As_4 pulse), and the ability for defect-free and abrupt growth interruptions, meeting the typical MBE standards. We demonstrate the possibility to grow defect-free zinc blende nanowires in the whole temperature window and to probe the growth dynamics in specially designed experiments.

9:30-9:50

We-C4

Control of the incubation time in the VSS growth of nanowires

M. Orrù(1)(2)(3), P. Rueda-Fonseca(1)(2)(3), A. Artioli(1)(2), M. Jeannin(1)(2), E. Bellet-Amalric(1)(3), M. den Hertog(1)(2)(3), E. Robin(1)(3), Y. Genuist(1)(2), R. André(1)(2), S. Tatarenko(1)(2), G. Nogues(1)(2), D. Ferrand(1)(2), J. Cibert(1)(2)

1- Université Grenoble-Alpes, 38000 Grenoble, France, 2 - CNRS, Institut NEEL, 38000 Grenoble, France, 3 - CEA, INAC, 38000 Grenoble, France

The growth of semiconductor nanowires by molecular beam epitaxy often involves the preparation of gold catalyst by dewetting under vacuum. Especially for ZnTe nanowires, this results in long incubation times for nanowire nucleation, growth of badly formed objects (loss of nanowires), and a length dispersion over a factor of ten on the same sample. Dewetting under Zn flux reduces the incubation time, gives the 80% of success rate of vertical nanowires, and only a factor of two in length mainly explained by the catalyst diameter dispersion. We correlate the success rate with the presence of different nanoparticle orientations after dewetting.

	Room A – 2D materials (graphene, MoS_2, WS_2,...)	Room B – Oxide and Hybrid Epitaxial Systems	
9:40-10:00	**We-A4** **Structural and electronic properties of two-dimensional hybrid stanene and graphene heterostructure** L. Wu(1), P. Lu(1)(3), D. Liang(1), C. Zhang(2), S. Wang(4)(5) *1 - State Key Laboratory of Information Photonics and Optical Communications, Ministry of Education, Beijing University of Posts and Telecommunications, P.O. Box 72, Beijing 100876, China. 2 - Beijing Computational Science Research Center, Beijing 100094, China. 3 - State Key Laboratory of Functional Materials for Informatics, Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, Shanghai 200050, China. 4 - Photonics Laboratory, Department of Microtechnology and Nanoscience, Chalmers University of Technology, 41296 Gothenburg, Sweden* Structural and electronic properties of two-dimensional hybrid stanene and graphene heterostructure (Sn/G) are studied with first-principles calculations. Various supercell models are constructed in order to reduce the strain induced by lattice-mismatch. The results show that stanene interacts overall weakly with graphene via van der Waals (vdW) interactions. Moreover, interlayer interactions in hybrid stanene/graphene heterostructure can induce tunable band gaps at stanene's Dirac point, and weak p-type and n-type doping of stanene and graphene, respectively, generatinga small amount of electron transfer from stanene to graphene. Interestingly, for model Sn(√7)/G(5), there emerges a band gap about 34meV overall the band structure.	**We-B4** **MBE Based Phase Control of Lithium Niobium Oxides** M. B. Tellekamp, J. C. Shank, W. A. Doolittle *Georgia Institute of Technology, Atlanta, Ga, USA* Epitaxial thin films of Nb, NbO, NbO_2, $LiNbO_2$, $LiNbO_3$, Li_3NbO_4, and $LiNb_3O_8$ are grown in a Molecular Beam Epitaxy chamber by a lithium controlled $NbCl_5$ chemistry under gaseous oxygen. It is shown that by combining a) the control of niobium incorporation rate using lithium catalysis of NbCl5 with b) varied substrate temperature a single phase of material phase can be grown. By controlling both coupled factors a) and b), high quality single phase materials can be obtained across a wide range of functionality, conduction, and bandgap, opening up opportunities for exciting multifunctional heterostructures and devices.	9:40-10:00
10:00-10:20	**We-A5** **High Temperature MBE of Graphene on Silicon Carbide, Sapphire and Hexagonal-Boron Nitride Flakes on Sapphire** T.S. Cheng(1), A. Davies(1)(2)(3), A. Summerfield(1), Y. J. Cho(1), V. V. Korolkov(1), J. Diez Albar(1), I. Cebula(1)(2), C.J. Mellor(1), A.N. Khlobystov(2)(3), T. Taniguchi(4), K. Watanabe(4), C.T. Foxon(1), L. Eaves(1), P.H. Beton(1), S. V. Novikov(1) *1 - School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, UK, 2 - School of Chemistry, University of Nottingham, Nottingham NG7 2RD, UK, 3 - Nottingham Nanoscale & Microscale Research Centre, University of Nottingham NG7 2RD, UK, 4 - The National Institute for Materials Science, Advanced Materials Laboratory, Tsukuba, Ibaraki 305-0044, Japan* We investigate the MBE growth of graphene using a dual-chamber VeecoGENxplor specially adapted to achieve high growth temperatures up to 1850°C. We use a solid carbon sublimation source to grow graphene at substrate temperatures between 1000 and 1650°C. The quality of the graphene layers is significantly improved by growing on hexagonal-BN. We observe a significant difference in the sticking coefficient of carbon on the surfaces of sapphire and h-BN flakes. The graphene layers have continuous domains with dimensions of ~20μm, and hexagonal moiré patterns are observed having large periodicities, up to 30nm, associated with high degrees of internal strain.	**We-B5** **Tin-Assisted Phase Stabilization of ε-Ga_2O_3 on c-plane Sapphire** M. Kracht, A. Karg, J. Schörmann, M. Eickhoff *I. Physikalisches Institut Justus-Liebig-Universität Gießen, Heinrich-Buff-Ring 16 D-35392 Gießen, Germany* Ga_2O_3 thin films were grown by plasma-assisted molecular beam epitaxy on c-plane sapphire with an additional tin flux. Plasma power and tin flux were varied. Dependent on the growth stoichiometry a phase change from β-Ga_2O_3 at oxygen-rich to ε-Ga_2O_3 at metal-rich conditions was observed, enabled by the presence of additionally supplied tin that inhibited the commonly observed Ga_2O-formation at these growth conditions. A combination of metal-rich growth conditions and the addition of tin during growth allow the stabilization of phase pure ε-Ga_2O_3.	10:00-10:20
10:20-10:50	Coffee break 10:20 – 10:50	Coffee break 10:20 – 10:50	10:20-10:50

Room C – Nanostructures: Nanowires	Notes

9:50-10:10

We-C5

Modeling of axial arsenide nanowire heterostructures formation

N. V. Sibirev(1)(2)(3), A. A. Koriakin(1)(2), V. G. Dubrovskii(1)(2)

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We present a model for the interfacial abruptness in axial arsenide nanowire heterostructures grown by the VLS method. The model applies to foreign-catalyzed (e. g. Au or Ag) heterostructures based on group III intermixing. We study the major factors influencing the composition and formulate some recipes for improving the interfacial abruptness. The interfacial abruptness of group III based, Au-catalyzed heterostructures should be improved for higher V flux or lower temperature. The interfaces become sharper with the growth interrupts at the flux commutation. Possibility to obtain a compositional modulation by just sharply changing the flux of the other group element has been found.

10:20-10:50

Coffee break
10:20 – 10:50

Room A – 2D materials (graphene, MoS_2, WS_2,...)

10:50-11:20

We-A6

Epitaxial Growth of Two-Dimensional Stanene and Artificial topological superconductors

Jin-feng Jia

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Ultrathin semiconductors present various novel electronic properties. The first experimental realized two-dimensional (2D) material is graphene. Searching 2D materials with heavy elements bring the attention to Si, Ge and Sn. Sn-based stanene has its unique properties. Stanene and its derivatives can be 2D topological insulators (TI) with a very large band gap as proposed by first-principles calculations, or can support enhanced thermoelectric performance, topological superconductivity and the near-room-temperature quantum anomalous Hall (QAH) effect. For the first time, in this work, we report a successful fabrication of 2D stanene by MBE. The atomic and electronic structures determined by STM and ARPES agree well with results by first-principles calculations. This work will stimulate the experimental study and exploring the future application of stanene. In the second part of the talk, I will discuss our recent efforts to make artificial topological superconductors by proximity effects and detect the Majorana mode in the vortex core. This work provides consistent evidences for the existence of Majorana fermions and also suggests a possible route to manipulating them.

11:20-11:40

We-A7

Atomically thin $MoSe_2$ nanostructures via van der Waals epitaxy

M.-W. Chen(1), D. Ovchinnikov(1), S. Lazar(2), O. Lopez-Sanchez(1), Andras Kis(1)

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Atomically thin $MoSe_2$ nanostructures were grown by molecular beam epitaxy (MBE) and characterized by Raman spectroscopy, x-ray photoelectron spectroscopy (XPS) and photoluminescence (PL). The two misoriented domains in monolayers(MLs) were revealed in scanning transmission electron microscopy (STEM) and account for the moiré patterns in the prevailing misoriented bilayers (BLs), implying that the ML edges act as preferential nucleation sites. The results not only demonstrate the large-area growth by MBE but alsoprovide insights for fundamental growth mechanism in van der Waals epitaxy.

11:50-18:00

Lunch + excursion
11:50 – 18:00

Room B – Oxide and Hybrid Epitaxial Systems

10:50-11:10

We-B6

Effective Surface Passivation of $In_{0.53}Ga_{0.47}As$ (001) using MBE- and ALD-HfO_2

M. Hong(1), P. Chang(2), T. D. Lin(1) H. W. Wan(1), Y. H. Chang(2), W.C. Lee(2), T. W. Pi(3), J. Kwo(4)

1 - Graduate Institute of Appl. Phys. and Dept. of Phys., Natl. Taiwan Univ., Taipei 10617, Taiwan 2 - Department of Materials Sci. and Engineering, Natl. Tsing Hua Univ., Hsinchu 30013, Taiwan 3 - National Synchrotron Radiation Research Center, Hsinchu 30076, Taiwan 4 - Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan

Both molecular-beam-epitaxy (MBE) and atomic-layer-deposition (ALD) high-κ HfO_2 has been in-situ deposited on pristine MBE-grown n- and p-$In_{0.53}Ga_{0.47}As$. The $HfO_2/In_{0.53}Ga_{0.47}As$ metal-oxide-semiconductor capacitors (MOSCAPs) all exhibit outstanding thermal stabilities up to 800°C, excellent C-V characteristics with true inversion behavior, and low leakage current densities of < 10^{-8} A/cm^2 at ±1 MV/cm. Moreover, interfacial trap densities (D_{it}'s) with no discernible peaks at the mid-gap were measured using the temperature-dependent conductance method.

11:10-11:30

We-B7

Achieving High MgO Content in Wurtzite ZnO Epilayer Grown on $ScAlMgO_4$ Substrate

M. C. Wen(1), T. Yan(2), L. Chang(1), M. M. C. Chou(1), N. Ye(2), and K. H. Ploog(1)

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Wurtzite ZnO and $Zn_{1-x}Mg_xO$ epilayers have been grown on $ScAlMgO_4$ (SCAM) substrates by molecular beam epitaxy. The X-ray diffraction, optical transmittance and cathodoluminescence data all indicate that the MgO content in the $Zn_{1-x}Mg_xO$ epilayer is as high as 50% (x=0.5) with no rocksalt phase being detected. In other words, the present study demonstrates that a high MgO content in ZnO can be achieved by growing the pseudobinary epilayer on the SCAM substrate with the assistance of a low lattice mismatch.

11:30-11:50

11:50-18:00

Lunch + excursion
11:50 – 18:00

Room C – Dilute Nitrides and Bismides: Dilute nitrides for solar cells

Notes

10:50-11:10

We-C6

Record Performance Dilute Nitride Solar Cells Grown by MBE

A. Freundlich(1), G.K. Vijaya(1), W. Wang(1), A. Mehrotra(1), K. Shervin(1), D. Tang (2), D. J. Smith(2)

1 - Center for Advanced Materials, University of Houston, Houston TX, USA, 2 - Physics Department Arizona State University, Tempe AZ, USA

In this work we report on the development by MBE of record performance 1-1.2 eV dilute nitride based solar cells. These results were made possible by combining (i) a carefully designed quantum engineered dilute nitride absorber design (that alleviates minority carrier lifetime/ poor carrier collection issues encountered in bulk dilute nitrides) with (ii) a somewhat unique optimization of the growth sequence (and plasma N nitrogen delivery system modification) that enabled superior interface sharpness control and improved optoelectronic properties.

11:10-11:30

We-C7

Strain-balanced type-II GaAsSb/GaAsN superlattices as 1 eV layer for efficient multi-junction solar cells

A.D. Utrilla(1), A. Gonzalo(1), D.F. Grossi(2), D.F. Reyes(3), V. Braza-Blanco(3), B. Alén(4), D.F. Marrón(5), P.M. Koenraad(2), T. Ben(3), D. González(3), A. Guzmán(1), A. Hierro(1), and J.M. Ulloa(1)

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Type-II GaAsSb/GaAsN superlattice (SL) structures are presented as a novel approach to remarkably improve the versatility of GaAsSbN and its suitability for 1 eV layers in tandem cells. The spatial separation of both Sb and N demonstrates an improved compositional control allowing an accurate control of the lattice-matching condition. Type-II SLs show a more efficient luminescence than the equivalent bulk and type-I GaAsSbN/GaAs SL counterparts, despite the longer radiative lifetimes, showing promising properties for an efficient carrier collection. The modification of the period thickness also allows a precise control over the absorption edge while additionally tuning the radiative carrier lifetimes.

11:30-11:50

We-C8

MQW and bulk 1 eV GaNAsSb solar cells

Aymeric Maros(1), Nikolai Faleev(1), Hongen Xie(2), Fernando A. Ponce(2), Christiana B. Honsberg(1) and Richard R. King(1)

1 - School of Electrical Computer and Energy Engineering, Arizona State University, Tempe, AZ 2 - Department of Physics, Arizona State University, Tempe, AZ

We report on the growth of 1 eV GaNAsSb solar cells lattice-matched to GaAs. After reviewing some of the growth challenges associated with this material, we will compare the performance of different solar cell configurations. To overcome the low minority-carrier diffusion length in these dilute nitride materials, we opted for p-i-n cell configuration. Both multi-quantum well (MQW) GaNAsSb/GaAs embedded within the intrinsic region and bulk GaNAsSb cells will be investigated and compared to a GaAs p-i-n reference cell.

11:50-18:00

Lunch + excursion

11:50 – 18:00

Room A – MBE fundamentals

8:30-9:00

Th-A1

Ab initio-based approach to novel behavior in semiconductor hetero-epitaxial growth

Tomonori Ito

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Novel behavior in hetero-epitaxial growth exemplified by InAs grown on GaAs(001) and (111)A is investigated using ab initio-based approach incorporating growth conditions such as temperature and beam equivalent pressure. Calculated surface phase diagrams reveal that InAs wetting layer (WL) favors (001)-(2x4)α2 and (111)A-(2x2) with In-vacancy at growth conditions consistent with experimental results. On the (111), In adsorption occurs with simultaneous As adsorption similar to homoepitaxial growth. On the other hand, the growth on the InAs(001)WL does not proceedwith simple In and As adsorptions but changes its surface structures to reduce large strain due to In adsorption.

9:00-9:20

Th-A2

Phase-Field modeling of semiconductor heteroepitaxy: elastic relaxation, surfaceenergy minimization and intermixing

Roberto Bergamaschini(1), Marco Albani(1), Marco Salvalaglio(2), Rainer Backofen(2), Axel Voigt(2), Leo Miglio(1), Francesco Montalenti(1)

1 - L-NESS and Department of Materials Science, University of Milano-Bicocca, via R. Cozzi 55, I-20125 Milano, Italy, 2 – Institut für Wissenschaftliches Rechnen, Technische Universität Dresden, D-01062 Dresden, Germany

A phase-field model allowing for the simulation of heteroepitaxial growth in semiconductors is developed. Both material deposition, mimicking Molecular Beam Epitaxy conditions, and surface diffusion, driven by the thermodynamic tendency toward free-energy minimization, are taken into account. The typical Stranski-Krastanow growth is investigated by considering the balance between surface energy, misfit strain and wetting effects. Additional contributions including substrate patterning, anisotropic surface energy and intermixing are introduced for a more realistic treatment. The finite element method is exploited for an accurate numerical solution. Simulation results are compared with experimental data.

9:20-9:40

Th-A3

Concurrent Coherent and Incoherent Growth Modes for GaAs/(In,Ga)As Core-Shell Nanowire Heterostructures

R. B. Lewis, L. Nicolai, M. Ramsteiner, H. Küpers, A. Trampert and L. Geelhaar

Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

We study strain relaxation in GaAs/(In,Ga)As core-shell nanowire heterostructures with systematic variations in In content and thicknesses by x-ray diffraction, Raman spectroscopy, and transmission electron microscopy. Above a critical In content, strain is plastically relaxed in three-dimensional mounds forming at the nanowire edges, and there is no critical thickness for this phenomenon. However, simultaneously coherently strained (In,Ga)As grows on the nanowire sidewalls. That both types of growth occur concurrently is generally not observed in planar heteroepitaxy and is attributed here to the presence of facets with different crystallographic orientation in close vicinity.

Room B – Dilute Nitrides and Bismides

8:30-8:50

Th-B1

MBE Growth and Characterization of Mid and Long IR InAsSbBi Compounds

Preston T. Webster(1), Arvind J. Shalindar(2), and Shane R. Johnson(1)

1 - Center for Photonics Innovation & School of Electrical, Computer, and Energy Engineering, Arizona State University, Tempe, AZ 85287, USA, 2 – Center for Photonics Innovation & School for Engineering of Matter, Transport, and Energy, Arizona State University, Tempe, AZ 85287, USA

The MBE growth and the structural and optical properties of pseudomorphic InAsSb, InAsBi, and InAsSbBi on GaSb will be presented. The growth surface is monitored using RHEED and the resulting materials examined using X-ray diffraction, Rutherford backscattering spectrometry, spectroscopic ellipsometry, and photoluminescence spectroscopy. (2x3) reconstructions indicate the presence of surface Sb or Bi during growth. X-ray diffraction and Rutherford backscattering spectrometry provide information on the bulk lattice constant and the mole fraction of the various alloys. Analysis of photoluminescence and ellipsometry measurements provide the bandgap and band edge energies as a function of mole fraction andtemperature.

8:50-9:10

Th-B2

Structural and Optical Properties of InGaAs/GaAsBi Type II Quantum Well

L. Yue(1), Y. X. Song(1), X. R. Chen(2), Q. M. Chen(1), X. Y. Wu(1) J. Shao(2), and S. M. Wang(1)(3)

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We demonstrate a new type II InGaAs/GaAsBi quantum well structure for long wavelength emission. The structure and optical properties are studied. 3.4% Bismuth (Bi) was incorporated in the GaAsBi QW layer. The room temperature photoluminescence is extended to 1230 nm, 82 nm longer than that of the type I GaAsBi QW with the same Bi content. The PL intensity is enhanced by more than ten times. The optical properties demonstrate that the type II dilute bismide QW has potential for the near and mid-infrared application.

9:10-9:40

Th-B3

Electromodulation spectroscopy of the electronic band structure in dilute nitrides and bismides

Robert Kudrawiec

Faculty of Fundamental Problems of Technology, Wroclaw University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

Dilute nitrides and bismides are very unusual semiconductor alloys since their electronic band structure cannot be interpolated within the virtual crystal approximation. Moreover these alloys are very challenging from the viewpoint of growth by MBE or other methods since a homogeneous incorporation of N and Bi atoms into III-V host and ensuring low concentration of native point effects are very difficult. Therefore for recent years a lot of attention was devoted to study the electronic band structure and optical properties for these alloys by electromodulation (EM) spectroscopy. This technique due to its absorptionlike character is a very powerful tool to investigate the optical transitions between the ground and excited states. Moreover EM allows to study the bandgap homogeneity in semiconductor alloys. This homogeneity and the optical quality can be evaluated on the basis of broadening of optical transitions observed in EM spectra. In this presentation the recent progress in the application of EM spectroscopy to study dilute nitrides and bismides will be summarized and discussed in the context of chemical trends.

Room C – Nanostructures: Quantum dots

Notes

8:30-8:50

Th-C1

Self-aligned hybrids of a plasmonic nanostructure and a single quantum dot

M. Zocher, Ch. Heyn, H. Runge, L. Pudewill, and W. Hansen

Institut für Festkörper und Nanostrukturphysik (INF), Universität Hamburg, Jungiusstraße 11, D-20355 Hamburg, Germany

Hybrids composed of a plasmonic nanostructure (PN) and a quantum dot (QD) single-photon emitter can yield functionalities that exceed those of the individual constituents. We discuss here a technique that allows the self-aligned positioning of both ingredients. As a central point, a GaAs QD as well as a PN are fabricated by filling of a nanohole. With distances of 10-30 nm the QDs are within the optical near-field to the PN. The nanoholes were created by local droplet etching (LDE) during molecular beam epitaxy (MBE) without any lithographic steps. First micro-photoluminescence measurements demonstrate clear exciton related optical features.

8:50-9:10

Th-C2

Site-controlled InAs Quantum Dots Coupled to Surface Plasmons

T. V. Hakkarainen(1), J. Tommila(1), A. Schramm(1), J. Simonen(1), T. Niemi(1), Ch. Strelow(2), T. Kipp(2), J. Kontio(1), and M. Guina(1)

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We report quantum dot-plasmon coupling in a hybrid structure consisting of site-controlled InAs/GaAs quantum dotchains in the proximity of an Ag film. The optical properties of the QDC-plasmon system are investigated using a cleaved-edge photoluminescence (PL) geometry, which allows us to probe the vertical and horizontal polarizations of the PL emission. We demonstrate plasmonic enhancement of both PL decay rate and vertical polarization of the PL emission with decreasing separation of the QDCs and the Ag film.

9:10-9:30

Th-C3

Origin of Spectral Brightness Variations in InAs/InP Quantum Dot Telecom Single Photon Emitters

Christopher J. K. Richardson(1), Richard P. Leavitt(1), Je-Hyung Kim(2), Edo Waks(2)(3), Bruce Arey(4), Ilke Arslan(4)

1 – Laboratory for Physical Sciences, University of Maryland, College Park, Maryland 20742, USA, 2 – Department of Electrical and Computer Engineering and Institute for Research in Electronics and Applied Physics, University of Maryland, College Park, Maryland 20742, USA, 3-Joint Quantum Institute, University of Maryland and the National Institute of Standards and Technology, CollegePark, Maryland 20742, USA, 4-Fundamental and Computational Science Directorate, Pacific Northwest National Laboratory, Richland, Washington 99352, USA

Long-distance quantum communication relies on the ability to efficiently generate and prepare single photons at telecom wavelengths. However, deterministic generation of indistinguishable single photons with high brightness remains a challenging problem. Circular InAs quantum dots spontaneously form on InP surfaces in a molecular-beam epitaxy system during cooling of a planar InAs layer that is grown at an elevated temperature. The importance of arsenic-for-phosphorus exchange reactions in the dot-formation process is evident in wavelength tuning through deterministic control of dot shape. Brightness suffers at 1.5 µm wavelengths, compared to 1.3 µm, which is attributed to defects forming in the larger dots.

9:30-9:50

Th-C4

Growth and optical properties of quantum ring-dot molecules grown byMultiple-Droplet Epitaxy process

M. Elborg, T. Noda, T. Kuroda, Y. Yao, and Y. Sakuma

National Institute for Materials Science, Tsukuba, Japan

We successfully grow coupled quantum Ring-Dot heterostructures by Multiple-Droplet Epitaxy. The growth is achieved by depositing GaAs quantum rings in a first droplet epitaxy process which are subsequently covered by a thin AlGaAs barrier. In a second droplet epitaxy process, Ga droplets selectively nucleate in the center indentation of the rings where they are crystallized. Micro-photoluminescence experiments reveal characteristic emission from ground and excited states of Rings and Ring+Dots unique to the structures. The flexibility in growth which allows to individually tune the Dot and Ring geometry offers great potential for creating complex quantum molecules for novel quantum information technologies.

Room A – MBE fundamentals

Th-A4

Reversible Nanoripple Formation of Ge Epitaxially Grown on High Miscut Si(001) Substrates

Christian Grossauer, István Daruka and Gunther Springholz
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Self-organized nanoripple formation of Ge on high miscut Si (001) substrates is studied using in vivo scanning tunneling microscopy and reflection high energy electron diffraction. We show that at temperatures below 600°C instead of Stranski-Krastanow islands a quasi periodic nanoripple pattern is spontaneously formed at critical coverages below 5 monolayers. Detailed investigations reveal that this ripple formation is perfectly reversible upon thermal cycling. For this reason, this process is attributed to a defaceting phase transition rather than the strain-induced SK growth instability. This opens novel pathways for nanopattering of Ge/Si surfaces.

9:40-10:00

Th-A5

3D GaP/Si(001) growth mode and antiphase boundaries

I. Lucci(1), S. Charbonnier(1), Y. Ping Wang(1), M. Bahri(3), M. Vallet(4), T. Rohel(1), R. Bernard(1), A. Létoublon(1), L. Largeau(3), G. Patriarche(3), A. Ponchet(4), O. Durand(1), L. Pedesseau(1), S. Gangopadhyay(5), P. Turban(2) and C. Cornet (1)
1 - UMR FOTON, CNRS, INSA Rennes, Rennes, F35708, France, 2 - IPR, UMR 6251, CNRS-Université de Rennes I, Campus de Beaulieu 35042 Rennes Cedex, France, 3 - Laboratoire de Photonique et Nanostructures, CNRS UPR 20, Route de Nozay, Marcoussis, 91460, France, 4 - CEMES-CNRS, Université de Toulouse, UPS, 29 rue Jeanne Marvig, BP 94347 Toulouse Cedex 04, France, 5 - Birla Institute of Technology & Science, Pilani, India

In this work, we investigate the relationship between the surface roughness and antiphase domains in GaP layers grown by MBE on a vicinal Si (001) substrate. The main role of the starting Si surface before III-V overgrowth is first discussed. Structural properties of antiphase domains (APDs) are investigated at the atomic scale by Scanning Tunneling Microscopy (STM) and Transmission Electron Microscopy (TEM). The correlation between the 3D growth mode and the emerging antiphase boundaries (APBs) is discussed in terms of surface/interface energy, supported by DFT calculations.

10:00-10:20

Room B – Dilute Nitrides and Bismides

Th-B4

Composition and Bandgap determination of MBE-grown GaInNAsSb

A. Aho(1), V.-M. Korpijärvi(1), R. Isoaho(1), P. Malinen(1), A. Tukiainen(1), M. Honkanen(2), M. Guina(1)
1 - Tampere University of Technology, Optoelectronics Research Centre, Korkeakoulunkatu 3, Tampere FI-33720, Finland, 2 - Tampere University of Technology, Department of Material Science, Korkeakoulunkatu 6, Tampere FI-33720, Finland

We report on an accurate composition determination method and a band gap model for GaInNAsSb. The composition determination method is based on a combination of x-ray diffraction and energy dispersive x-ray spectroscopy measurements. We propose a modified band anti-crossing model of GaInNAs for precise prediction of band-gap values for GaInNAsSb. The accuracy for determining the band-gap is 20 meV. The determination accuracy for the group V atoms of GaInNAsSb is estimated to be +/-0.005. The studied composition range for the layers grown by molecular beam epitaxy were 0–0.06, 0–0.17 and 0–0.08, for N, In and Sb respectively.

9:40-10:00

Th-B5

Resonant Zener Tunnelling via Zero-Dimensional States in the Novel Mid-Infrared Alloy In(AsN)

D.M. Di Paola(1), M. Kesaria(2), O. Makarovsky(1), A. Velichko(1), A. Krier(2), A. Patanè(1)
1 - School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, UK, 2 - Physics Department, Lancaster University, Lancaster LA1 4YB, UK

We report on a new type of Zener tunnelling that involves the resonant transmission of electrons through zero-dimensional (0D) states. To observe this phenomenon we have created a p-i-n diode in which a narrow quantum well of the mid infrared alloy In(AsN) is placed in the intrinsic (i) layer. The incorporation of nitrogen in the quantum well creates 0D states localized over nanometer lengthscales. These states provide “stepping stones” for electrons tunnelling from the n- to the p-side of the diode, thus leading to enhanced conductivity and negative differential resistance that is weakly dependent on temperature.

10:00-10:20

10:20-10:50

Coffee break
10:20 – 10:50

Coffee break
10:20 – 10:50

10:20-10:50

Room A – MBE fundamentals

Th-A6

Metal Modulated Epitaxy of GaN at High Growth Rates >9µm/hr

E.A. Clinton, B.P. Gunning, J.J. Merola, W.A. Doolittle
Georgia Institute of Technology, Atlanta, Georgia 30332, USA

A modified plasma-assisted molecular beam epitaxy chamber equipped with a high flow mass flow controller for nitrogen, an increased conductance aperture plate, and increased pumping capacity, has resulted in remarkably higher growth rates up to 8.4 µm/hr with 34 sccm of N^2 when employing the metal modulated epitaxy growth technique. Seeding the plasma with argon enhanced the growth rate up to 9.8 µm/hr at 600 W radio frequency power. These high growth rates required switching to Ge for suitable n-type films, gave unintentional residual doping ~10^{15} cm^{-3}, resulted in smooth surfaces exhibiting step flow growth, and excellent crystal quality.

10:50-11:10

Room B – II-VI compounds

Th-B6

MBE growth and magnetic properties of Fe-doped ZnTe thin films

Y. Sugimura(1), T. Nakamura(1), T. Domon(1), S. Ishitsuka(1), K. Kanazawa(1), S. Kuroda(1), M. Mitome(2), Y. Bando(2), H. Ofuchi(3)
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We investigated structural and magnetic properties of $Zn_{1-x}Fe_xTe$ thin films with a high Fe composition up to x = 0.25 grown by MBE. As a result, it was revealed that these properties change depending on the VI/II flux ratio during the growth. In the growth with an excess supply of Te flux, precipitates of extrinsic phases are formed at x > 0.02 and the grown films exhibit paramagnetism. On the other hand, in the growth with an excess supply of Zn flux, Fe-rich nanocolumn regions, which seem to be structurally coherent to the host matrix, are formed and the grown films exhibit room-temperature ferromagnetism at x > 0.06.

10:50-11:10

Room C – Nanostructures: Quantum dots

Notes

9:50-10:20

Th-C5

III-V Semiconductor Nanostructures for Coupling to Photonic Crystal Microcavities

Y. González(1), J. Herranz(2), I. Prieto (3), P. A. Postigo (1), D. Fuster (1), L. Wewior(1), B. Alén(1), L. González(1)

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Photonic crystal microcavities (PCMs) with embedded quantum dots (QDs) may open doors to efficient quantum photonic devices. A single QD embedded in a PCM becomes an efficient emitter provided that both spectral and spatial matching of the optical cavity mode and the QD optical emission occurs. In this work, we present two different approaches towards the fabrication of coupled QD-cavity system: 1) by predefining the QD position at the maximum of the electric field of a pre-fabricated PCM and 2) by fabricating a PCM around a buried QD whose position and wavelength emission are previously determined.

10:20-10:50

Coffee break
10:20 – 10:50

Room C – Nanostructures: Quantum dots

Notes

10:50-11:10

Th-C6

GaSb quantum dots on (001)GaP for nonvolatile nanoflash memories

X. Wallart(1), C. Coinon(1), D. Troadec(1), L. Desplanque(1), Y. Wang(2), P. Ruterana(2), L. Bonato(3), D. Bimberg(3)(4)

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GaSb quantum dots on GaP are predicted to exhibit longer hole storage times than ever reported, an essential prerequisite for novel nanoflash memories. The critical thickness for their formation by MBE is observed by us to be around 1 monolayer and does not depend on the growth conditions. Their influence on the dot density and shape is analyzed in the framework of scaling theory. After capping, TEM reveals a strong shape change of the QDs, which remain coherent. The valence band offset determined by XPS is 0.6-0.8 eV in good agreement with the hole localization energy measured by capacitance spectroscopy.

11:10-11:30

Room A – MBE fundamentals

Th-A7

High-temperature Molecular Beam Epitaxy at Substrate Thermocouple Temperatures up to 1850°C

T.S. Cheng(1), Y. Cho(1), A. Summerfield(1), A. Davies(1)(2), J. Diez Albar(1), V. V. Korolkov(1), C. J. Mellor(1), A. N. Khlobystov(2), T. Taniguchi(3), K. Watanabe(3), L. Eaves(1), P. H. Beton(1), C.T. Foxon(1), S. V. Novikov (1)

1 - School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, UK, 2 - School of Chemistry, University of Nottingham, Nottingham NG7 2RD, UK, 3 - The National Institute for Materials Science, Tsukuba, Ibaraki 305-0044, Japan

The dual GENxplor has been specially modified by Veeco to achieve growth temperatures of up to 1850°C in ultra-high vacuum conditions and is capable of growth on rotated substrates of up to 3 inches in diameter. In MBE, the substrate temperature is normally measured using an optical pyrometer. Because we use transparent SiC and sapphire substrates, the pyrometer measures the temperature of the substrate heater, not the substrate surface. Therefore, our estimate of the growth temperature is based on a thermocouple reading. We will discuss new challenges in the operation of high-temperature MBE with examples of graphene and boron nitride epitaxy.

11:30-11:50

Th-A8

Optimization of metamorphic buffers for MBE growth of high quality AlInSb/InSb quantum structures

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We present a study on optimizing metamorphic buffers for InSb/InAlSb growth on GaAs substrates in [001] and [001] offcut 2° towards [100] directions. Just three repeats of $Al_{0.24}In_{0.76}Sb/Al_{0.12}In_{0.88}Sb$ interlayers buffers lowered the dislocation density to 2×10^7 cm^{-2}. Although spiral hillocks up to 50nm-high were observed at dislocation outcrops for the on-orientation substrates, their sidewalls offer atomically smooth, dislocation free areas of up to 500×1500nm in size, suitable for the growth and subsequent top-down fabrication of InSb nanowires. While no hillocks were observed for 2° off substrates, the morphology is dominated by deep surface depressions with no clear location of dislocation outcrops.

11:50-12:10

12:20-13:40

Lunch
12:20 - 13:40

Room B – II-VI compounds

Th-B7

Effect of epitaxial strain on spin configuration of individual transition metal ions in quantum dots.

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In this work we investigate influence of strain, resulting from lattice mismatched epitaxial heterostructures, on spin configuration of transition metal ions embedded in novel quantum dots (QDs) systems: CdSe/ZnSe QDs with single Fe^{2+} and CdTe/ZnTe with single Co^{2+} ion. We show that strain induces qualitative change the Fe^{2+} ground state: from nonmagnetic, nondegenerate state in bulk host to magnetic, doubly degenerate state with spin projection Sz = ±2 in strained QD. We also present direct determination of Co^{2+} anisotropy by observation of very weak, partially allowed optical transitions for which initial and final state of Co^{2+} is not the same.

11:10-11:30

Th-B8

Nonpolar homoepitaxial (10-10) ZnO/ZnMgO multilayers: from strain relaxation to optical microcavities

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Homoepitaxial nonpolar ZnO/ZnMgO multilayers have been used to fabricate distributed Bragg reflectors and optical microcavities, with the aim of studying the exciton/cavity photon strong-coupling regime and fabricate, in fine, room-temperature polariton lasers. The strain relaxation mechanisms operating in these heterostructures have been identified, and their impact on the microcavities photonic properties characterized. Overall, the homoepitaxial approach introduced in this work provides a means to improve the optical properties of ZnO-based microcavities in the linear regime, and close the gap with more mature material systems commonly employed in the field of polaritonics.

11:30-11:50

Th-B9

Formation of Au-catalyzed ZnTe and ZnTe/PbTe nanowires on (001) GaAs by MBE : from planar to out-of-plane growth

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We report growth kinetic studies of gold-catalyzed ZnTe nanowire (NWR) condensates on (001) GaAs substrates by molecular beam epitaxy (MBE). It is found that NWRs change the growth direction from initially in-plane to out-of-plane when they intersect and cross on the substrate surface. Formation of in-plane NWRs at the initial stages of growth prior to out-of-plane ones is explained by taking the free energy of droplet/substrate interface into account. Possibility of growth of PbTe quantum dots (QD) on ZnTe nanowire surface is demonstrated and paves way for development of highly efficient multiple exciton generation (MEG) devices.

11:50-12:10

12:20-13:40

Lunch
12:20 - 13:40

Room C – Nanostructures: Quantum dots

Notes

11:10-11:30

Th-C7

Control of In-Ga intermixing in InAs quantum dot on nitrogen δ-doped GaAs

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We studied the growth of InAs quantum dots (QDs) on nitrogen (N) δ-doped GaAs(001). N-δ doping has two opposite effects on the Ga incorporation from the underlying layer into the QDs. One is the enhancement of Ga incorporation induced by the lattice strain due to the smaller radius of N atoms. The other is an effect blocking for Ga incorporation due to the large bonding energy of Ga-N or In-N. At a low N-sheet density, the lattice-strain effect was dominant, while the blocking effect became larger with increasing N-sheet density. Thereby, the emission wavelength of InAs QDs was shifted.

11:30-11:50

Th-C8

InAs quantum dots grown directly on unpatterned Si(100) on-axis substrates

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The direct growth of III-V quantum dots on unpatterned Si(100) is important for the achievement of monolithically integrated light sources on the Si platform. Here, we report the growth of InAs/GaAs quantum dots on Si(100) substrates without patterns or offcut. InAs/GaAs quantum dot layers were grown using a thin buffer layer of $Al_{0.4}Ga_{0.6}As$ - GaAs - $Al_{0.3}Ga_{0.7}As$.Due to the quantum dots unique insensitivity to non-radiative defects, the samples preserve the high optical properties of samples grown on GaAs substrates: The emission linewidth of our InAs quantum dots is only 29.8 meV, whilst maintaining 20% intensity of samples grown on GaAs. This result represents a key step towards the realization of monolithically integrated silicon photonics.

11:50-12:10

Th-C9

GaAs Quantum Dot Molecules Filled into Droplet Etched Nanoholes

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We fabricate self-aligned vertically stacked GaAs quantum dot molecules (QDMs) by filling of self-assembled nanoholes in AlGaAs. The tunable nanoholes are created using local droplet etching (LDE) combining conventional molecular beam epitaxy growth with self-assembled lithography-free top-down patterning. The optical emission from single strain-free QDMs shows clear excitonic features with linewidths below 100 µeV after optimizations of the fabrication process. This allows investigations of resonant coupling between the individual dots forming a QDM. Dependent on a vertical electrical field, we observe direct and indirect excitons and anti-crossings between them which clearly indicate resonant molecule states.

12:20-13:40

Lunch
12:20 - 13:40

Room A – Dilute Nitrides and Bismides: Dilute bismides

13:40-14:10

Th-A9

Spontaneous Formation of Bi-rich Nanostructures During MBE Growth of Ga(As,Bi): The Impact of Surface Processes and Bi Segregation

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The inherent miscibility gap of Ga(As,Bi) alloys can be exploited to create highly uniform Bi-rich nanostructures embedded in a quantum confinement structure. In this work we report on the spontaneous formation of Bi-rich units in Ga(As,Bi)/GaAs epilayers and quantum wells due to lateral composition modulations occurring during MBE growth. Whereas the Bi-rich nanostructures are created via two dimensional phase separation at the growing surface, our results suggest that the process is assisted by a Bi segregation mechanism more complex than expected, implying both lateral and vertical (surface segregation) mass transport. The impact of surface reconstructions is also discussed.

14:10-14:30

Th-A10

Molecular Beam Epitaxy and characterization of high Bi content GaSbBi alloys

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The epitaxial growth, structural and optical properties of $GaSb_{1-x}Bi_x$ layers are reported. The incorporation of Bi into GaSb is varied in the range 0 < x 13% by varying the growth temperature and V/III BEP ratio. The incorporation of Bi and the structural properties were determined by X-ray diffraction. The optical properties and surface morphology have been studied by photoluminescence measurements and optical microscopy, respectively. The samples show a smooth, droplet free surface until 9% Bi incorporation. Photoluminescence measurements at room temperature of the GaSbBi sample with 13% Bi incorporation indicate emission at 3.8 μm.

14:30-14:50

Th-A11

Growth and characterization of quaternary GaInAsBi layers for optoelectronic applications

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GaInAsBi layers were grown on GaAs substrate and their alloy composition, structural characteristics, as well as the optical and electrical parameters were determined. It has been found that by simultaneous incorporation of Bi and In into the lattice of GaAs the energy bandgaps as narrow as 0.6 eV can be obtained. The obtained epitaxial layers of quaternary bismide alloy have shorter than 1 ps carrier lifetimes and relatively large dark resistivity evidencing that this material is a good candidate for ultrafast optoelectronics applications.

Room B – Spintronics and Topological Materials

13:40-14:00

Th-B10

Realization of a vertical topological p–n junction in Sb_2Te_3/Bi_2Te_3 heterostructures

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We show a direct experimental proof of a vertical topological p–n junction made of a heterostructure of two different binary 3D TI materials n-Bi_2Te_3 and p-Sb_2Te_3 epitaxially grown by molecular-beam epitaxy on Si(111). We demonstrate that the chemical potential is tunable by about 200meV when decreasing the upper Sb_2Te_3 layer thickness from 25 to 6nm without applying any external bias.

14:00-14:20

Th-B11

Epitaxial Growth and Characterization of $Bi_{1-x}Sb_x$ Spin Hall Alloy on GaAs(111) Substrates

Yugo Ueda and Pham Nam Hai

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We grew $Bi_{1-x}Sb_x$ thin films on GaAs(111) substrates by molecular beam epitaxy. By optimizing the growth condition, we were able to grow $Bi_{1-x}Sb_x$ epitaxially with the Sb concentration ranging from 0 to 100%. In situ RHEED observation as well as XRD measurements confirmed that single crystalline $Bi_{1-x}Sb_x$ thin films were grown with the epitaxial orientation of $Bi_{1-x}Sb_x$(001) // GaAs(111). The growth phase diagram of $Bi_{1-x}b_x$ was consistent with theoretical calculations. The conductivity of $Bi_{1-x}Sb_x$ exceeds $10^5\ \Omega^{-1}m^{-1}$, which is higher than those of other Bi-based topological insulators by an order of magnitude.

14:20-14:40

Th-B12

Natural Ordering of Homologous Superlattice Structures of Bi-Chalcogenide Topological Insulators grown by MBE and Controlled by Stoichiometry

G. Springholz(1), O. Caha(2), V. Holy(3), D. Kriegner, H. Steiner(1), S. Wimmer(1), V. Volobuev(1), A. Ney(1), M. Partha(4), J. Sanchez-Barriga(4), A. Varykhalov(4), O. Rader(4), G. Bauer (1)

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We report a detailed study of the structural properties of stoichiometry controlled $Bi_2Te_{3-\delta}$ and $Bi_2Se_{3-\delta}$ layers grown by molecular beam epitaxy using different Bi to Te(Se) flux ratios. It is shown that a spontaneous ordering in the form of natural superlattice structures occurs, where in order to accommodate the deficit of Te or Se, Bi double layers are inserted in between the quintuple layers of the 2:3 crystal structure. While for $Bi_2Te_{3-\delta}$ this occurs rather randomly, for $Bi_2Se_{3-\delta}$ quite well ordered superstructures are formed. The effect of incorporation of magnetic dopands such as Mn induced a similar perturbation of the quintuple layer structures of these compounds and the effect on twinning is also derived.

14:40-15:00

Th-B13

Self-assembled InAs Quantum Dots for Quantum Communication and Spin Manipulation

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Self-assembled InAs quantum dots (QDs) show promise as quantum emitters for quantum information processing. By making only minimal changes to the recipe for the QD growth over several growth campaigns, insights into the impact of other growth parameters on the quality of the QDs as quantum emitters are gained. Integrating high-quality QDs in devices with optimized photon extraction efficiency, significant increases in entangled photon generation and spin measurement fidelity were shown.

Room C – MBE grown Devices: Lasers

Notes

13:40-14:00

Th-C10

GaSb lasers grown on Silicon substrate for telecom application

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We report the first GaSb-based laser monolithically grown on Silicon substrate working in CW mode at room temperature with an emission in the telecom wavelength range (1.59µm). We will present the laser design, Silicon *ex-situ* preparation, technology process and electro-optics characterization.

14:00-14:20

Th-C11

InAs/GaAs Quantum Dot Lasers Grown on Si Substrates

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Si based light emitting source has been considered as “holy grail” to Si photonics. By growing III-V materials on Si substrates, the advantages of III-V and Si could be combined. In this paper, we have demonstrated InAs/GaAs quantum dot (QD) lasers monolithically grown on Si substrate with electronically pumped continues-wave operation. The very low threshold current density of 62.5 A cm^{-2}, a room-temperature output power exceeding 105 mW and operation up to 120 °C have been achieved. Over 3,100 h of continuous-wave operating data have been collected. This work brings the possibility of Si optoelectronic integration circuits.

14:20-14:40

Th-C12

1.3 µm quantum-dot micro-disk lasers directly grown on (001) silicon

Alan Y. Liu(1), Yating Wan2(), Qiang Li(2), Evelyn L. Hu(3), Kei May Lau(2), Arthur C. Gossard(1), John E. Bowers(1)

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We report growth and room temperature continuous wave operation of InAs quantum-dot microdisk lasers grown on nominal (001) silicon substrates. The active structure containing five layers of InAs/GaAs quantum dots was grown by MBE on a GaAs-on-v-grooved-Si (GoVS) template produced by MOCVD. Microdisk lasers with 4 µm diameters showed continuous wave lasing at room temperature with thresholds on the order of hundreds of microwatts. A statistical comparison with identical lasers on native GaAs substrates shows that average threshold values for the two cases are within 40% of each other despite four orders of magnitude difference in dislocation density.

14:40-15:00

Th-C13

MBE Growth of GaSb based VECSEL structures for emission wavelength 1.9 to 2.8 µm

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The Performance of GaSb based VECSEL traditionally peaks around 2.0 µm wavelength and drops significantly for longer wavelength. We present MBE growth concepts to achieve almost wavelength independent high performance with external quantum efficiencies around 50% and optical output powers ~ 7 W up to 2.5 µm and attempts towards emission wavelength around 2.8 µm. Key parameters are the control of strain of ternary and quaternary quantum wells as well as the precise balance of the ensemble pump wavelength, emission wavelength, resonance wavelength and distributed feedback mirror.

Room A – Dilute Nitrides and Bismides: Dilute bismides

14:50-15:10

Th-A12

Optimization of growth parameters for GaAsBi using stationary growth

J. Puustinen, J. Hilska, M. Guina

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Interplay between the MBE growth parameters and the material properties of GaAsBi layers is studied using a stationary growth method which produces continuous source flux gradients over the substrate. Structural investigation reveals several growth regimes where Bi incorporation and surface properties are modified with respect to the As/Ga flux ratio. Photoluminescence reveals a narrow window of flux ratios providing optimum emission intensity, with variations in the emission shape and wavelength. The stationary growth method reveals the high sensitivity of material properties to flux ratios and provides means to study a range of growth parameters within a single growth run.

15:10-15:30

Th-A13

Anomalous photoluminescence in $InP_{1-x}Bi_x$

Xiao Yan Wu(1), Xi Ren Chen(2), Wen Wu Pan(1), Peng Wang(1), Li Yao Zhang(1), Yao Yao Li(1), Hai Long Wang(3), Kai Wang(1,2), Jun Shao(2) and Shu Min Wang(1,4)

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Low temperature photoluminescence (PL) from $InP_{1-x}Bi_x$ thin films with Bi concentrations in the 0-2.49% range reveals anomalous spectral features with strong and very broad (linewidth of 700 nm) PL signals compared to other bismide alloys. Multiple transitions are observed and their energy levels are found much smaller than the band-gap measured from absorption measurements. These transitions are related to deep levels confirmed by deep level transient spectroscopy, which effectively trap free holes and enhance radiative recombination. The broad luminescence feature is beneficial for making super-luminescence diodes, which can theoretically enhance spatial resolution beyond 1 µm in optical coherent tomography (OCT).

Room B – Late News

15:00-15:20

Th-B14

Ultra-Low Charge and Spin Noise in Self-Assembled Quantum Dots

Arne Ludwig(1)(2), Jonathan H. Prechtel(2) Andreas V. Kuhlmann(2) Julien Houel(2)(3), Sascha R. Valentin(1), Andreas D. Wieck(1) and Richard J. Warburton(2)

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Self-assembled $In_xGa_{1-x}As$ quantum dots (QDs) are promising hosts for spin qubits with excellent coupling to photons. Nuclear spin and charge fluctuations lead to dephasing and limit the applicability of QDs as qubits. We show that charge noise can be minimized by high quality MBE growth of well-designed heterostructures yielding natural linewidths down to 1.15 µeV. To minimize the nuclear spin noise, one direction would be to reduce the wave function overlap with the nuclei. We show that this is indeed the case for a single hole spin in a QD that we embedded in the intrinsic region of an n-i-p-diode. For random nuclei, the heavy-hole limit is achieved at neV energies; equivalent to dephasing times of microseconds.

15:30-16:00

Coffee break
15:30 – 16:00

Coffee break
15:30 – 16:00

Room A – Nanostructures : InAs nanostructures

16:00-16:20

Th-A14

Self-alignment of InAsnanostructures on (631) and (775) High-Index Substrates

E. Eugenio-López(1), J. A. Espinoza-Figueroa(1), I. E. Cortes-Mestizo(1), A. Yu. Gorbatchev(2), S. Shimomura(3), V. H. Méndez-García(1)

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The self-alignment of InAs quantum nanostructures on high-index GaAs(631)- and GaAs(775) substrates is studied. The variation of the arsenic pressure (P_{As}) in the growth of GaAs buffer layers resulted on corrugated surfaces, allowing the self-organization of InAs nanostructures. The nanostructures grown on (631)A and B substrates were aligned along [1-13]. The (775)- samples showed quantum dashes and quantum wires. The photoluminescence emission of the (631)A samples disappears with increasing P_{As}, while for B-type samples the PL emission intensity is only attenuated.

Room B – Wide Bandgap semiconductors: Applications

16:00-16:20

Th-B15

(Al,Ga,In)N-on-Silicon Microdisk Lasers

F. Semond(1), M. Mexis(1), J. Sellés(2), C. Brimont(2), G. Cassabois(2), P. Valvin(2), T. Guillet(2), I. Rolland(3), Y. Zeng(3), X. Checoury(3), P. Boucaud(3), and B. Gayral(4,5)

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Optimizing epitaxial growth of AlN on Si(111) using ammonia-MBE, efficient GaN/AlN quantum wells are grown on a thin AlN buffer layer. Microdisk photonic resonator exhibiting high optical quality factors are fabricated using the etching selectivity between the nitride epilayer and the silicon substrate. A deep-UV microlaser operating at 275 nm at room temperature is demonstrated under optical pumping opening the way to future developments of nitride nanophotonic platforms on silicon.

Room C – MBE grown Devices: Lasers

Notes

15:00-15:20

Th-C14

Epitaxy of InP-based VCSELs for light emission at 2.5 µm and beyond

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Type-II quantum wells are a promising concept to extend the emission wavelength of InP-based vertical-cavity surface-emitting lasers beyond 2.3 µm, while keeping a very well established material platform and process technology. This concept integrates type-II aligned GaInAs/GaAsSb QWs in a laser with an InP cavity and an epitaxial GaInAs/InP back- and an amorphous top-mirror. The exact control of the cavity length and the emission wavelength of the quantum wells are of crucial importance to realize laser devices. The presented devices are working single-mode in continuous-wave operation up to 10°C at a wavelength of 2.49 µm.

15:30-16:00

Coffee break
15:30 – 16:00

Room C – MBE grown Devices: IR lasers and photodetectors

Notes

16:00-16:20

Th-C15

High-power terahertz quantum cascade lasers grown by molecular beam epitaxy

Lianhe Li, Li Chen, Joshua Freeman, Rui Dong, Paul Dean, Edmund H. Linfield, and A. Giles Davies

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We demonstrate high-power terahertz frequency quantum cascade lasers grown by molecular beam epitaxy. The devices operate in pulsed mode with emission frequency of ~4.6 THz, a maximum working temperature of 115 K, and a maximum peak output power of ~430 mW from a single facet.

Room A – Nanostructures: GaN-based NWs

16:20-16:40

Th-A15

Te-doped Self-catalyzed InAs Nanowires on Si (111) Substrates

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We report about the growth, morphological properties and electrical characterization of Te-doped InAs nanowires (NWs). The NWs are grown self-catalyzed by molecular beam epitaxy on Si (111) substrates using vapor-solid (VS) approach. The Te dopant is provided by effusion of stoichiometric GaTe source material. The increase of the Te beam flux over a certain limit has a strong influence on the NW morphology, decrease of NW length and increase of NW diameter. DC electrical measurements are used to prove the doping of the InAs NWs.

16:40-17:00

Th-A16

Nucleation and growth mechanism of self-catalyzed InAs nanowires on silicon

U. P. Gomes(1), D. Ercolani(1), V. Zannier(1), J. David(2), M. Gemmi(2), F. Beltram(1), and L. Sorba(1)

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We report on the nucleation and growth mechanism of self-catalyzed InAs nanowires grown on Si (111) substrates by chemical beam epitaxy. With a careful choice of the growth parameters, we demonstrate that NWs can nucleate from an In droplet and grow by the vapor-liquid-solid mechanism while sustaining an In droplet at the tip. The experimental data are analyzed within suitable theoretical model.

17:00-17:20

Th-A17

Broadening Length Distributions of Au-catalyzed InAsNanowires

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In this work we present a generic model that is capable of describing length non-uniformity of Au-catalyzed VLS-grown nanowires (NWs). We compare experimental data for the length distributions of nanowires grown by chemical beam epitaxy with Au catalyst nanoparticles obtained by thermal de-wetting and colloidal Au droplets. The Poissonian length distributions are observed in the first case. Whereas colloidal Au particles produce broader and asymmetric length distributions. Within our model, we quantitatively explain observed behaviors by accounting for the incubation time for nanowire growth.

17:20-17:40

Th-A18 Late news

InAs/AlSb core-shell nanowires with enhanced optical properties for phototransistors

Q. D. Zhuang(1), H. Alradhi(1), X. R. Chen(2), J. Shao(2), H. H. Fang(2), W. D. Hu(2), S. H. Hu(2), Z. M. Jin(1), A. M. Sanchez(3)

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High-quality InAs/AlSb core-shell nanowires were synthesized by molecular beam epitaxy via droplet-assisted technique. The core-shell nanowires exhibit an areal density of density of 1.3×10^{9} cm^{-2}, diameter of 74.6±15.0 nm and length of 2.0±1.0 um. The nanowires have a perfect interface between the core InAs and the shell AlSb without presence of dislocations. We demonstrate that the core-shell structures result in a significantly enhanced optical property which was attributed to the passivated surface. We also demonstrate the use of such core-shell nanowires as phototransistors for efficient infrared photodetection.

Room B – Wide Bandgap semiconductors: Applications

16:20-16:40

Th-B16

Hybrid MOCVD-MBE tunnel junction contacts for III-Nitride LEDs and lasers

E.C Young, B.P. Yonkee, J. Leonard, F. Wu, D.A. Cohen, S.P. DenBaars, S. Nakamura, and J.S. Speck

Materials Department, University of California, Santa Barbara, CA, 93106, USA

Efficient tunnel junctions (TJ) provide a means of carrier conversion between p-type and n-type material in semiconductor devices and are potentially advantageous for the III-Nitride material system, where the poor conductivity of p-GaN impacts the design and efficiency of light emitting and laser diodes (LEDs and LDs). In this paper, we describe development of a hybrid growth approach that involves growing the active region of devices and top p-GaN layers by the standard (MOCVD) growth technique, followed by growth of the highly doped n-side of the TJ by ammonia-assisted molecular beam epitaxy. Device results on TJ LEDs, edge emitting and vertical cavity lasers will be presented.

16:40-17:00

Th-B17

ZnO/GaN DBRs grown by plasma-assisted molecular beam epitaxy

D. Adolph and T. Ive

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We demonstrate for the first time ahybrid ZnO/GaN distributed Bragg reflector. The structures were grown by plasma-assisted molecular beam epitaxy utilizing the same growth chamber for continuous growth of both ZnO and GaN without exposing the sample to the ambient. The Bragg mirror swere comprised of up to 20 ZnO/GaN pairs. The peak reflectance measured was 77% at 500 nm and had a 32nm wide stopband. The samples were grown along both (000-1) and (0001) directions. A two-step low-temperature deposition of a buffer layer followed by high-temperature growth of the epitaxial layer significantly improved the Bragg mirror reflectivity.

17:00-17:20

Th-B18

Linear and Nonlinear Behavior of Intersubband Transitions at 1.55 µm in Cubic GaN/AlN Multi Quantum Well Structures

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1 - Department of Physics, University of Paderborn, 33098 Paderborn, Germany, 2 - Experimentelle Physik 2, TU Dortmund University, 44227 Dortmund, Germany

We study the linear and nonlinear optical response of cubic GaN/AlN multi quantum well structures with various barrier thicknesses. The linear intraband absorption reveals a broad emission centered at 0.7 eV. A comparison of the transition energies with calculations employing a commercial Schrödinger-Poisson solver gives a good match. Furthermore, the optical nonlinearity is measured with a pump probe setup, revealing ultrafast intersubband relaxation times of < 100 fs. Also the third order nonlinear optical susceptibility is estimated to $Im(\chi^{(3)}) \sim 1.1 \quad 10^{-20}$ m^2/V^2.

17:20-17:40

Th-B19 Late news

Vertical Transport in Isotype InAlN/GaN dipole induced diodes by combined Ammonia and Plasma Assisted Molecular Beam Epitaxy

M. N. Fireman(1), E. C. H. Kyle(1), E. Ahmadi(2), H. Li(2), U. K. Mishra(2), J. S. Speck(1)

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Isotype InAlN/GaN dipole induced diodes are grown by a combination of NH_3-MBE and PAMBE MBE on both Ga and N Polar orientated substrates. While simulations predict barriers to electron vertical transport greater than 1 eV, extracted barrier heights are less, in agreement with previous results on ternary alloy nitride barriers. Nonetheless, improvement in rectification is observed with growth optimization. Orientation related morphology differences are also observed and discussed. N-Polar structures show good agreement between forward and reverse bias extracted barrier heights, an interesting result considering the impurity uptake challenges of N-polar growth.

Room C – MBE grown Devices: IR lasers and photodetectors

Notes

16:20-16:40

Th-C16

MBE Growth of Type-I Interband Cascade Lasers near 3.2µm

J.A. Gupta(1), G. C. Aers(1), E. Dupont(1), J.-M. Baribeau(1), X. Wu(1), Y. Jiang(2), L. Li(2), R. Q. Yang(2) and M. B. Johnson(3)

1 - National Research Council of Canada, Ottawa, ON K1A 0R6 Canada, 2 - School of Electrical and Computer Engineering, University of Oklahoma, Norman, OK 73019 USA, 3 - Homer L. Dodge Dept. of Physics and Astronomy, University of Oklahoma, Norman, OK 73019 USA

Type-I interband cascade laser structures were grown on GaSb substrates using solid-source molecular beam epitaxy. The structures employ strain-balanced InAs/AlSb superlattice cladding layers surrounding a GaSb waveguide containing the six-stage ICL active region. Each active region stage has a single InGaAsSb QW, with an 8-QW InAs/AlSb electron injector and a 3-QW GaSb/AlSb hole injector. The devices operate in continuous-wave mode at room temperature with an emission wavelength near 3.2µm.

16:40-17:00

Th-C17

High operation temperature mid-wavelength interband cascade infrared photodetectors grown on InAs substrate

Yi. Zhou, Jianxin. Chen, Zhicheng Xu, Li He

Key Laboratory of Infrared Imaging Material and Detectors, Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai 200083, China

We will report our recent studies on interband cascade infrared photodetectors (ICIP) grown by molecular beam epitaxy (MBE) on InAs substrates aiming for operation at high temperature. We grew and fabricated different ICIP structures. Our result showed the two-stage ICIP has a QE of 41.4% at the temperature of 180K and 19.8% at 300K. The three-stage ICIP has a R_0A of 2.06×10^5 Ω.cm^2 at 120K and 32.1 Ω.cm^2 at 200K. The Johnson-noise limited detectivities of the two-stage and three-stage device reach to 4.1×10^{10} cm·Hz$^{1/2}$/w and 6.2×10^{10} cm·Hz$^{1/2}$/w, respectively, at 200K. The 300 K background limited infrared performance (BLIP) operation temperature is estimated to be over 140 K.

17:00-17:20

Th-C18

Room Temperature Operation of Laterally Biased Quantum Well Infrared Photodetectors

Álvaro Guzmán(1), Raquel Gargallo-Caballero(1), Xiang Lü(2), and Holger T. Grahn(2)

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In this work, we develop a novel quantum infrared (IR) photodetector with a lateral biasing scheme. The active region of the device contains two *n*-doped GaAs/(Al,Ga)As quantum wells, each one contacted by means of an AuGe metallization. The device has been fabricated by alternative steps of MBE growth and in situ plasma etching inside the vacuum chamber. An intense room temperature IR photocurrent peak has been observed at 21 µm, in good agreement with the simulations. These results pave the way for the development of a new generation of quantum IR detectors to be used in room temperature applications.

17:20-17:40

Th-C19 Late news

Electrically pumped continuous wave III-V quantum dot lasers epitaxially grown on exact GaP/Si (001)

Alan Y. Liu(1), Jon Peters(2), Justin Norman(1), Xue Huang(3), Daehwan Jung(1), Minjoo Larry Lee(4), Arthur C. Gossard(1)(2), John E. Bowers(1)(2)

1 - Materials Department, University of California Santa Barbara, Santa Barbara, California, USA, 2 - Department of Electrical and Computer Engineering, University of California, Santa Barbara, Santa Barbara, California, USA, 3 - Hewlett-Packard Labs, Palo Alto, California, USA, 4 - Department of Electrical and Computer Engineering, University of Illinois, Urbana-Champaign, Illinois, USA

We report room temperature continuous wave operation of electrically pumped III-V semiconductor lasers epitaxially grown on exact (001) GaP/silicon substrates without offcut.

Room A – Wide Bandgap semiconductors: Growth

Fr-A1

Pure and Disordered Group III Nitride Heterostructures: Growth and Physical Properties

J. S. Speck

Materials Department, University of California, Santa Barbara, CA 93106, USA

MBE growth of GaN and its alloys has advanced to the level where its is now the technique that has demonstrated the highest quality group III nitride layers and heterostructures. In this presentation we review our work on three main topics: (i) the realization of high electron mobility and high hole mobility bulk GaN by NH_3 MBE. The work on p-GaN demonstrates the importance of reduced growth temperature to avoid natural compensation by native donors. (ii) For lateral electron devices, we demonstrate the realization of pure AlN interlayers (via atom probe tomography) by plasma-assisted MBE for AlGaN/AlN/GaN and InAlN/AlN/GaN high electron mobility transistors. The pure AlN interlayer allows the realization of record low sheet resistance 2DEGs. (iii) We demonstrate the surprising role that natural alloy fluctuations play in the vertical transport through nominal alloy heterobarriers. In all of these studies, MBE has played an essential role in understanding the physical properties of the group III nitrides.

9:00-9:30

Fr-A2

In situ strain relaxation study of GaN layers grown on AlN by NH_3-MBE

P. Sohi, D. Martin, N. Grandjean

Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland

The relaxation of GaN layers epitaxially grown by NH_3-MBE on AlN were studied *in situ by* monitoring the in-plane lattice parameter deduced from the RHEED pattern. The critical thickness for the onset of plastic relaxation varies from 4 to 17 monolayers depending on substrate temperature and V/III ratio. In addition, the relaxation rate at low temperatures is very slow and therefore fully relaxed GaN layers are reached after few tens of nanometers. Control of the relaxation process of GaN on AlN is an important parameter when growing on silicon substrate or fabricating GaN/AlN heterostructure based devices.

9:30-9:50

Fr-A3

AlN growth by NH_3-MBE on Si (111): High Temperature growth

Sebastian Tamariz, Denis Martin, J-F Carlin and Nicolas Grandjean

Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL) CH-1015 Lausanne, Switzerland

We present insitu measurements using reflection high energy electron diffraction of the transition from two dimensional layer-by-layer to step flow growth mode. We have found that the growth mode changes to step flow for temperatures above 1050°C for a NH_3 beam equivalent pressure (BEP) of 1.1 x 10^{-4}, Al BEP of 8 x 10^{-8}Torr and a growth rate of 160 nm/hr. Smooth surfaces showing monolayer height step-edges are obtained, as revealed by atomic force microscopies (AFM). In addition, we observed a drastic improvement of the crystalline quality of AlN layers deposited on Si(111) substrate.

9:50-10:10

10:10-10:40

Coffee break
10:10 - 10:40

Room B – MBE grown Devices

Fr-B1

Volatile and Non-Volatile Lithium Niobite Memristors Grown by MBE

M. B. Tellekamp, J. C. Shank, W. A. Doolittle

Georgia Institute of Technology, Atlanta, Ga, USA

Lithium Niobite ($LiNbO_2$), a lithium intercalated sub-oxide of hexagonal symmetry, is grown by Molecular Beam Epitaxy (MBE) and fabricated into basic structures for testing as analog memristors. $LiNbO_2$ is grown on sapphire at 975°C and fabricated into memristor devices showing resistance modulation and hysteresis as a function of potential and frequency of excitation. Volatile devices are fabricated using lithium blocking electrodes, while non-volatile devices are fabricated with a lithium-alloying electrode as the center contact of a concentric device. It is shown that this structure exhibits enhanced and non-volatile resistance modulation on the order of biological long term plasticity rules.

9:00-9:20

Fr-B2

Patterned Back Gates suitable for Ultra-High Mobility GaAs/AlGaAs Heterostructure Epitaxy

M. Berl(1), L. Tiemann(1), W. Dietsche(1), H. Karl(2), W. Wegscheider(1)

1 - Solid State Physics Laboratory, ETH Zürich, 8093 Zürich, Switzerland, 2 - Lehrstuhl für Experimentalphysik IV, Universität Augsburg, 86159 Augsburg, Germany

We have developed a method to implement patterned back gate structures into the growth of ultra-high mobility MBE heterostructures. The back gate structures are defined by local oxygen ion implantation into a silicon doped GaAs epilayer grown on top of a semi-insulating GaAs substrate. The oxygen ion implantation suppresses the conductance without affecting the surface quality, allowing for high quality heterostructure growth. First measurements have demonstrated a wide range of tunability ($2*10^{10}$ cm^{-2} to $4.4*10^{11}$ cm^{-2}) for a two-dimensional electron system (2DES) grown on an implantation patterned substrate with mobilities exceeding $20*10^6$ cm^2/Vs.

9:20-9:40

Fr-B3

GaSb-based Optoelectronic Devices – New Developments in Industry

K. Vizbaras, A. Vizbaras, A. Trinkūnas, I. Šimonytė, E. Dvinelis, J. Aleknavičius

Brolis Semiconductors UAB, Moletu pl. 73, Vilnius, Lithuania

We present new developments and trends in the global market of optoelectronics in terms of potential enabling applications of GaSb-based optoelectronic devices. The focus is directed to light emitters that offer unique advantages for future enabling applications in medical, environmental, industrial and defence market segments. Manufacturability and mass-market compatibility is addressed and different approaches to low-cost and enhanced functionality are reviewed. Finally, our recent progress on new generation systems and solutions for medical and defence systems is presented covering requirements and experimental performance of our MBE-grown chips to final system requirements and performance.

9:40-10:10

Coffee break
10:10 - 10:40

10:10-10:40

	Room C – III-V compounds	Notes
9:00-9:20	**Fr-C1** **GaSb grown by molecular beam epitaxy on silicon substrates** J.-B. Rodriguez(1)(2), K. Madiomanana(1)(2), L. Cerutti(1)(2), and E. Tournié(1)(2) *1 - Univ. Montpellier, IES, UMR 5214, F- 34000, Montpellier, France, 2 - CNRS, IES, UMR 5214, F- 34000, Montpellier, France* This paper presents our latest results on the hetero-epitaxy of antimonide-based semiconductors on silicon substrates. X-ray diffraction techniques as well as AFM were used to analyze the GaSb layer quality of several samples comprising AlSb nucleation layers grown with different growth conditions. We found that the defects governing the material quality are different at elevated and low temperature.	
9:20-9:40	**Fr-C2** **On the origin of threading dislocations during III-Sb epitaxy on Si(001)** M. Niehle(1), J.-B. Rodriguez(2)(3), L. Cerutti(2)(3), K. Madiomanana(2)(3), E. Tournié(2)(3), A. Trampert(1) *1 - Paul-DrudeInstitutfürFestkörperelektronik, Hausvogteiplatz 5–7, 10117 Berlin, Germany, 2 - Université de Montpellier, IES, UMR 5214, F-34000 Montpellier, France, 3 - CNRS, IES, UMR 5214, F-34000 Montpellier, France* The origin of threading dislocations in large lattice mismatched system of III-Sb grown by MBE on vicinal Si(001) substrates is investigated by electron tomography and scanning transmission electron microscopy (STEM). The tomographic reconstruction of the AlSb wetting layer to Si demonstrates an island-like morphology with high degree of coalescence. Complementary STEM measurements reveal the location of threading dislocations. The number and distribution of these threading defects cannot be made consistent with the concept of their formation during island coalescence based on imperfections in the misfit dislocation network. On the other hand, the detection of 60°-type dislocations at the interface is outlined and their contribution to the formation of threading dislocations is discussed.	
9:40-10:00	**Fr-C3** **Structural and elastic properties of interfaces in [InAs/AlSb] multilayers** M. Vallet(1), Y. Claveau(1), B. Warot-Fonrose(1), C. Gatel(1), H. Tang(1), N. Combe(1), C. Magen(2), R. Teissier(3), A. N. Baranov(3), A. Ponchet(1) *1 - Centre d'Elaboration de Matériaux et d'Etudes Structurales, CEMES CNRS, and Université de Toulouse, France, 2 - Laboratorio de Microscopıas Avanzadas, Instituto de Nanociencia de Aragon (LMA - INA), ARAID and Departamento de Fısica de la Materia Condensada, Universidad de Zaragoza, Spain, 3 - IES CNRS-UMR 5214, Université Montpellier II, 34095 Montpellier, France* [InAs/AlSb] multilayers are widely used for quantum cascade lasers (QCLs) emitting in the middle infrared range. The interfaces can be either formed by Al-As or In-Sb bonds. The resulting strains can be high; strains were used here as a probe to explore the actual composition of the interfaces and then get insights on the mechanisms of the interface formation. Thanks to high quality atomic resolved STEM-HAADF images, strain analysis revealed a very high level of negative strain, showing the strong Al-As type character of the interfaces. Elastic properties of interfaces were also modelled at the atomic scale by DFT.	
10:10-10:40	Coffee break 10:10 - 10:40	

Room A – Wide Bandgap semiconductors: InGaN

10:40-11:00

Fr-A4

Compositionally Graded InGaN Layers On Vicinal N-face GaN Substrates

K. Hestroffer(1), N. Lu(2), Q. Wang(2), C. Lund(1), H. Li(1), M. J. Kim(2), U.K. Mishra(1), S. Keller(1)

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Compositionally graded $In_xGa_{1-x}N$ films are grown by plasma-assisted molecular beam epitaxy on vicinal (000-1) GaN base layers and exhibit a bright photoluminescence signal at room-temperature in the whole visible range. Graded films with a final In mole fraction of 0.15 are strained-relaxed and their surfaces exhibit an interlacing finger structure composed of crests and depressions. The fingers are elongated along the miscut direction of the GaN base layer and are characteristic of a Ga-deficient growth regime on a vicinal surface. Cross sectional high resolution transmission electron micrographs suggest that dislocations terminate at the depressions.

11:00-11:20

Fr-A5

Molecular Beam Epitaxy of In(Ga)N monolayer in GaN matrix

X.Q. Wang(1), X.T. Zheng(1), Z.Y. Chen(1), D.Y. Ma(1), X. Rong(1), P. Wang(1), B. Shen(1), T. Schulz(2) and M. Albrecht(2)

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We report the successful growth of InGaN monolayer in GaN matrix by molecular beam epitaxy, as confirmed by the measurement of scanning transmission electron microscopy. Cathodoluminescence (CL) mapping study shows excellent in-plane uniformity of the inserted InGaN monolayer. The carrier dynamics in the 2D InGaN have also been investigated by temperature-dependent, time-resolved and excitation-power-dependent photoluminescence (PL), proving the recombination occurs via confined excitons in the inserted InGaN monolayer. This work indicates that such structure affords an interesting opportunity for developing high-performance photonic devices.

11:20-11:40

Fr-A6

InN/GaN Short Period Superlattices grown by Plasma Assisted MBE

M. Siekacz(1)(2), G. Staszczak(1), T. Suski(1), E. Grzanka(1)(2), H. Turski(1), T. Ernst(2), T. Schulz(3), M. Albrecht(3) and C. Skierbiszewski(1)(2)

1 - Institute of High Pressure Physics, Polish Academy of Sciences, Sokolowska 29/37, 01-142 Warszawa, Poland, 2 - TopGaN Ltd, Sokolowska 29/37, 01-142 Warszawa, Poland, 3 - Leibniz-Institute for Crystal Growth, Max-Born-Str. 2 12489 Berlin, Germany

In this paper we investigate 1 monolayer thick (ML) InN/GaN short period superlattices (SPSL) grown by Plasma Assisted Molecular Beam Epitaxy (PAMBE) on GaN c-polar substrates with different in-plane lattice parameter-a. The change of the lattice constant-a was obtained using relaxed $In_XGa_{1-X}N$ (thickness changed form 150 - 500 nm) buffer with average indium content about x = 20%. Strong shift in PL emission to longer wavelength for SPSL grown on relaxed InGaN is the result of the change In content in monolayer of InN related with change of substrate lattice parameter-a.

11:40-12:00

Fr-A7

Epitaxial Growth and Characterization of ScAlN on GaN and SiC Substrates

M.T. Hardy(1), D. F. Storm(2), N. Nepal(2), B. P. Downey(2), D. S. Katzer(2), and D. J. Meyer(2)

1 - NRC Postdoctoral fellow residing at the Naval Research Laboratory, 4555 Overlook Ave SW, Washington, DC, USA, 2 - Naval Research Laboratory, 4555 Overlook Ave SW, Washington, DC, USA

Novel alloys between conventional III-nitrides and transition metal nitrides, such as ScAlN, will lead to a new class of functional wide-bandgap materials with enhanced piezoelectric response. Wurtzite $Sc_xAl_{1-x}N$ thin films with $x \approx 0.2$ are demonstratedusing plasma-assisted molecular beam epitaxy. The ScAlN thin films have smooth surface morphology, with rms surface roughness as low as 0.7 nm. X-ray diffraction rocking curve measurements indicate a 0002 reflection full width at half maximum as low as 468 arcsec for a near lattice-matched 73 nm $Sc_{0.17}Al_{0.83}N$ on GaN and 1013 arcsec for a 200 nm thick $Sc_{0.19}Al_{0.81}N$ film grown directly on SiC.

Room B – Late news

10:40-11:00

Fr-B4

CdTe/MgCdTe double-heterostructures and solar cells grown by MBE on lattice-matched InSb substrates

Yong-Hang Zhang, Xin-Hao Zhao, Calli Campbell, Maxwell Lassise, Brian Tracy, Jacob Becker, Yuan Zhao, Mathieu Boccard, David Smith, Zachary Holman

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This abstract reports the MBE growth and characterization of crystalline CdTe/MgCdTe double-heterostructures on lattice-matched InSb substrates. These structures demonstrate very long carrier lifetime (3.6 µs) and ultra-low interface recombination velocity (1.2 ± 0.7 cm/s). Solar cells constructed with a double-heterostructure absorber in conjunction with a p-type a-Si:H layer as the hole contact demonstrate record open-circuit voltages up to 1.1 V and a maximum efficiency over 20%.

11:00-11:20

Fr-B5

InGaN Laser Diodes with Tunnel Junctions for Hole Injection Grown by Plasma-Assisted MBE

C. Skierbiszewski(1)(2), G. Muziol(1), M. Siekacz(1)(2), H. Turski(1), A. Feduniewicz-Zmuda(1), K. Szkudlarek(1), S. Grzanka(1)(2), P. Perlin (1)(2)

1 - Institute of High Pressure Physics, Polish Academy of Sciences, Sokolowska 29/37, 01-142 Warsaw, Poland, 2 - Top-GaN Ltd., Sokolowska 29/37, 01-142 Warsaw, Poland

We demonstrate for the first time edge emitting nitride laser diodes (LDs) with tunnel junctions (TJ) for hole injection grown entirely by one epitaxy technology - by plasma assisted molecular beam epitaxy. The LDs operate in continuous wave mode at 450 nm. The application of the TJ eliminates the need for use of p-type contact. We believe that this demonstration open new possibility for design and processing of nitride based laser diodes.

11:20-11:40

Fr-B6

Revealing Dirac fermions in strained three-dimensional HgTe topological insulators via Quantum Hall spectroscopy

C. Thomas(1), O. Crauste(2), C. Bäuerle(2), L. P. Lévy(2), E. Orignac(3), D. Carpentier(3), P. Ballet(1), and T. Meunier(2)

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Quantum Hall regime with well-defined Hall resistance plateaus and vanishing longitudinal resistances is evidenced in our thin three-dimensional HgTe topological insulator structures. Temperature dependent analysis of the Quantum Hall effect enables direct demonstration of Dirac fermions in these structures. We also demonstrate that the coupling between the top and bottom topological surface states leads to a degeneracy lifting of the Landau levels through a mechanism specific to these Dirac surface states. Our study demonstrates the relevance of such thin sample three-dimensional topological insulators in the design of quantum circuits based on novel Dirac states.

11:40-12:00

Fr-B7

Highly N-doped Ge Microdisks with Circular Bragg Gratings on Ge-on-Insulator

H. Hashimoto, X. Xu, K. Sawano, T. Maruizumi

Advanced Research Laboratories, Tokyo City University, 8-15-1 Todoroki, Setagaya-ku, Tokyo 158-0082, Japan

We have fabricated germanium (Ge) microdisks with circular Bragg gratings (CBGs) on highly n-doped germanium-on-insulator (GOI) substrate. The GOI substrate is fabricated by wafer bonding from Ge grown on Si substrate by solid-source molecular beam epitaxy, and highly n-type doping concentration of 9×10^{19} cm^{-3} is achieved by phosphorus diffusion from a spin-on-dopant source. Photoluminescence spectra show very sharp Fabry-Perot resonance with high contrast fringes and Q-factors over 200 near the direct band gap of Ge, which is far superior to microdisks without CBGs. The results indicate that GOI microdisks with CBGs are promising candidate for realizing Ge lasers.

Room C – Nanostructures: GaN-based NWs

Notes

10:40-11:00

Fr-C4

Self-Assembled Formation of Dense Ensembles of Long, Thin, and Uncoalesced GaN Nanowires on Crystalline Ti films

D. van Treeck, G. Calabrese, J. Goertz, J. Bartolomé Vilchez, A. Trampert, O. Brandt, S. Fernández-Garrido, L. Geelhaar

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We investigate in detail the self-assembled nucleation and growth of GaN nanowires (NWs) on crystalline Ti films. In contrast to the behavior on Si and many other substrates, on Ti for the optimum substrate temperature the number density does not increase dramatically anymore once the NWs have nucleated. Hence, this type of substrate allows for the growth of long, thin, and largely uncoalesced GaN NWs of reasonable density and fairly homogenous length. This improved morphology of the NW ensemble enables the fabrication of well-defined (In,Ga)N/GaN axial heterostructures and is a promising basis for core-shell structures on the non-polar sidewall facets.

11:00-11:20

Fr-C5

Self-Organized Vertical GaN Nanocolumns Grown on Silica Glass by RF-Molecular Beam Epitaxy

A. Liudi Mulyo(1)(2), Y. Konno(2), B. O.Fimland(1), H. Weman(1)(2), K. Kishino(2)

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Self-organized GaN nanocolumns (NCs), employing no external catalyst, were successfully grown on fused silica by radio frequency-molecular beam epitaxy (RF-MBE). We studied systematically the evolution of NC structure and photoluminescence (PL) peak intensity as a function of substrate temperature, Ga flux and N_2 flow rate. Under optimized growth conditions, the NCs can be formed at high density with the *c*-axis maintained perpendicular to the substrate surface and with generated PL peak intensities higher than ahydride vapor phase epitaxy grown commercial GaN substrate. This finding paves the way to the application of GaN NC structures in light emitting diodes using amorphous silica glass as a substrate.

11:20-11:40

Fr-C6

Manipulation of the Optical and Structural Properties of $In_xGa_{1-x}N$ Nanowire Heterostructures by Varying the Plasma Source Operating Parameters

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$In_xGa_{1-x}N$ offers a direct bandgap that is tunable from the ultraviolet to the infrared spectral range which renders it a promising material to exploit the advantages of nanowire (NW) structures for future nano-optical applications. Group III-nitride NWs are grown under nitrogen-rich growth conditions by plasma-assisted molecular beam epitaxy. Here, we have investigated the impact of the plasma source operating parameters on the growth of InxGa1-xN NWs. In particular, the influence of the nitrogen flux and the forward power on the morphological and optical properties of $In_xGa_{1-x}N$/GaN NWs is studied.

11:40-12:00

Fr-C7

Shape Evolution of (In,Ga)N Quantum Disc Stacks Embedded in GaN Nanowires

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In this work the evolution of the width to thickness (w/t) ratio along the stacking sequence of (In,Ga)N multiple quantum discs (QD) embedded in GaN nanowires (NW) is studied, and its possible relation with the vertical strain interaction between the QDs discussed. An inverse correlation between the w/t ratio and the measured average strain in the barrier below is found, and a cumulative strain effect proposed as the driving force of the change in shape of the QDs.

Auditorium Einstein

12:00 - 13:00

Student award presentation
and
Closing session

12:00 - 13:00

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POSTER SESSIONS

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2D materials (graphene, MoS2, WS2,...)

Mo-P-1

MBE growth of 2D- layered chalcogenides materials: Bi_2Se_3 and GaSe

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We present here a study of the MBE growth and electronic properties of the layered chalcogenides Bi_2Se_3 and GaSe on GaAs (111)B and graphene-SiC substrates. Factors determining the crystalline quality of layered films are discussed, in particular the effect of the substrate on single or multi-domain formation during growth and the effect of growth conditions on the density of intrinsic electronic defects in these layered thin films.

II-VI compounds

Mo-P-2

Potential exchange between anions (Se, Te) or cations (Cd, Zn, Mn) at the surface of II-VI layers

R. André(1)(2), B. Bonef(1)(4), C. Bougerol(1)(2), H. Mariette(1)(2), A. Grenier(1)(5), M. Den Hertog(1)(2), P.H. Jouneau(1)(4), E. Bellet-Amalric(1)(3)

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We grew, by MBE, a series of binary II-VI compounds (CdTe, ZnTe, CdSe, ZnSe) to investigate the competition for incorporation within element II, or within element VI. We systematically saturated the layer surface with a chosen element and subsequently exposed it to another one of the same column in the periodic table. For anions, we show that Se substitutes very efficiently previously incorporated Te, whereas Se is robust to Te exposure. For cations, Mn replaces Cd or Zn, whereas Zn and Cd are balanced.

Mo-P-3

$Cu_2ZnSnSe_4$ thin film grown by molecular beam epitaxy on GaAs

Y. Curé(1)(2), V. Reita(1)(3) , S. Pouget(1)(2) and H. Boukari(1)(3)

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$Cu_2ZnSnSe_4$ has a potential to be used as an absorber in thin film solar cells and is only made of non toxic and abundant elements. Here we report on $Cu_2ZnSnSe_4$ layers grown by molecular beam epitaxy on GaAs(100). The samples were investigated by Reflection of High Energy Electron Diffraction, Raman spectroscopy, X-Ray Diffraction, Scanning electron microscopy and photoluminescence. The best layers were grown at around 450°C with a clear orientation of the c-axis along the growth direction. No secondary phases could be detected in the layers, except $CuGaSe_2$ and $CuGaZnSe_3$ that are attributed to intermixing at the GaAs/$Cu_2ZnSnSe_4$ interface.

Mo-P-4

CdTe/Zn(Mg)(Se)Te quantum dots for single photon emitters grown by MBE

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We report on MBE growth of CdTe/Zn(Mg)(Se)Te quantum dots(QDs) with low surface density, which could be potentially used for single photon emitters applications. The CdTe/Zn(Mg)(Se)Te QD structures were grown by using a surface energy variation technique which implies covering the CdTe strained 2D layer with amorphous Te, followed by fast thermal desorption of the latter accompanied by a 2D-3D RHEED pattern transition (so called QDs thermal activation technique). The influence of MBE growth parameters and the QD structures design on their photoluminescence properties are discussed.

II-VI compounds

Mo-P-5

Peculiarities of the growth of (Zn,Mn)O by plasma-assisted MBE

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CRHEA-CNRS, Rue Bernard Gregory, 06560 Valbonne, France

In this communication, we will present the growth studies carried out on (Zn,Mn)O that lead us to evidence peculiarities in the growth of (Zn,Mn)O which are directly linked to the incorporation of Mn, and have not been encountered for the growth of other magnetic-oxide alloys.

II-VI compounds

Mo-P-6

Influence of the sapphire substrate surface treatment on the domain structure of the ZnTe epilayer

T. Nakasu(1), W. Sun(1), M.Kobayashi(1)(2) and T. Asahi(3)

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We focused on the cleaning the sapphire substrate with a mixture of H_2SO_4 and H_2O_2, and ZnTe thin films were grown on the H_2SO_4 and H_2O_2 cleaned substrate by MBE. The crystal quality of the ZnTe layer was studied by means of XRD pole figure and low-temperature PL measurements. It was investigated that the crystallinity of the thin film would be affected by the chemical state of the surface

Mo-P-7

Antireflective Photonic Structure with CdTe/(Cd,Zn,Mg)Te Quantum Dots containing single Mn ions

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1 - Institute of Experimental Physics, Faculty of Physics, University of Warsaw, ul. Pasteura 5,02-093 Warsaw, Poland, 2 - Institut Néel, CNRS et Université Joseph Fourier, Grenoble Cedex 9 F-38042, France

This work presents application of (Cd,Zn,Mg)Te Distributed Bragg reflectors for enhancement of CdTe/(Cd,Zn,Mg)Te QDs photoluminescence and for decrease of laser reflectivity through efficient cavity mode. We presentspectroscopy of individual CdTe/(Cd,Zn,Mg)Te QD with a single Mn ion, grown on such Bragg mirrors forming antireflective structure. The realized structures are employed in the four-wave mixing experiments on individual QDs, to investigate their coherent nonlinear response.

Mo-P-8

Enhancement of the critical thickness of CdSe/ZnSe quantum wells via the strain compensation technique

T. Rieger(1)(2), T. Riedl(3), J. K. N. Lindner(3) A. Pawlis(1)(2)

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The lattice mismatch between CdSe and ZnSe is known to limit the thickness of CdSe quantum wells on ZnSe (100) to about 2-3 monolayers. We demonstrate that this thickness can be improved by alternating layers of tensile und compressively strained materials resulting in an efficient strain compensation. This method enables to achieve CdSe/ZnSe quantum wells with CdSe thicknesses ranging from 1 to 6 monolayers, covering the whole visible spectrum. The strain compensation effect is investigated by high resolution transmission electron microscopy and supported by molecular statics simulations.

Spintronics and Topological Materials

Mo-P-9

Fabrication and Ferromagnetism of Si-SiGe/MnGe Core-Shell Nanocolumns

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Quasi one-dimensional geometry of Si-$Si_{0.5}Ge_{0.5}$(30nm)/$Mn_{0.08}Ge_{0.92}$(20nm) core-shell nanocolumns is fabricated. XRD results show the SiGe layer is fully relaxed. It is found that the ferromagnetic properties and T_C heavily depend on the growth temperature of MnGe layer, the Si-SiGe/MnGe core-shell nanocolumn sample in which the MnGe layer was grown at 300°C has a highest T_C of 260 K, a lower (250°C) and a higher (350°C) growth temperatures for this layer will result in a decrease of ferromagnetism. The origin of the ferromagnetism is discussed in combination with microstructure results of the samples.

Mo-P-10

Doping and magnetism in the intrinsic ferromagnetic semiconductors GdN

C.-M. Lee(1), F. Natali(1), S. Vezian(2), M. Al Khalfioui(2)(3), H. Warring(1), B. Damilano(2), J. Trodahl(1), B. Ruck(1)
1 - Centre de Recherche sur l'Hétéro-Épitaxie et ses Applications (CRHEA), Centre National de la Recherche Scientifique, Rue Bernard Gregory, 06560 Valbonne, France, 2 - MacDiarmid Institute for Advanced Materials and Nanotechnology, School of Chemical and Physical Sciences, Victoria University of Wellington, PO Box 600, Wellington, New Zealand 3 - Université de Nice Sophia Antipolis, Parc Valrose, 06102 Nice Cedex 2, France

Diluted ferromagnetic semiconductors (DMS), which are formed by a dilute concentration of magnetic atoms incorporated into semiconductor materials, are the front-runner for semiconductor spintronics. In such system the magnetic dopants tend to act as electronic dopants too, making it difficult to control independently the carrier concentration and the magnetism. In this context the rare-earth nitrides (REN) appear as attractive alternatives as they are intrinsic ferromagnetic semiconductors. However nominally undoped epitaxial REN films show an n-type conductivity with electron carrier densities above 10^{20} cm^{-3}, due to nitrogen vacancies. We show that the electron concentration in REN can be controlled by intentional doping with magnesium without affecting significantly the magnetic properties.

Mo-P-11

Combining Rare Earth Nitrides and Group-III Nitrides for Semiconductor-based Spintronics

S. Vézian(1), J. Chan(2), H. Warring(2), M. Al Khalfioui(1)(3), B. Damilano(1), J. Massies(1), J. Trodahl(2), B. Ruck(2), F. Natali(2)
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The rare earth nitrides (RENs) are almost unique, displaying the properties of both semiconductors and ferromagnets, even in their intrinsic state, thus offering opportunities across a broad range of electronic-optical technologies and "semiconductor-based spintronics" applications. To date the research on the RENs has mainly focused on the fundamental properties, both from experimental and theoretical point of views. One particular aspect in this field that has been largely overlooked is the question of the epitaxial growth. Here, we will take stock of where our progress has occurred in combining epitaxially the RENs with group-III nitrides (AlN, GaN).

Mo-P-12

High-resolution characterization of HgTe/CdTe topological interfaces

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Topological nature as well as quantized transport are demonstrated on HgTe/CdTe structures grown by molecular beam epitaxy. In order to fully understand the transport mechanisms occurring at the topological insulator interfaces, a set of high-resolution characterizations has been performed using X-rays as well as transmission electronic microscopy. The latter is preferred as it gives access to localized strain and chemical information at the interfaces.

Spintronics and Topological Materials

Mo-P-13

Growth by MBE and characterization of GdN and SmN thin films

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The control of the epitaxial growth of rare earth nitrides (REN) as well as understanding their physical properties remain a challenge to consider the development of new spintronic devices. We report on the growth of samarium nitride (SmN) and gadolinium nitride (GdN) thin films by molecular beam epitaxy on (0001) AlN/Si templates. *In-situ* characterizations (STM, RHEED) and *ex-situ* (XRD and Hall Effect) will be presented and discussed in relation with the growth conditions.

Mo-P-14

In-situ fabrication of epitaxial superconducting contacts on MBE-grown topological insulators

P. Schüffelgen(1), D. Rosenbach(1), M. Lanius(1), M. Eschbach(2), P. Gospodaric(2), C. Weyrich(1), N. Demarina(1), E. Neumann(3), S. Trellenkamp(3), L. Plucinski(2), M. Luysberg(4), T. Schäpers(1), G. Mussler(1), D. Grützmacher(1)
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We introduce an alternative way of defining contact pads on top of device structures. Aluminum is directly grown by molecular-beam epitaxy on topological insulator thin films. Depending on the thickness of the aluminum, it either works as a fully oxidized protection layer or as epitaxial contacts. The different areas are defined by shadow masks, respectively.

Mo-P-15

Temperature-induced transition of magnetic anisotropy between in-plane and out-of-plane directions in GaMnAs film

Sangyoep Lee(1), Seonghoon Choi(1), Seul-Ki Bac(1), Taehee Yoo(1)(2), Hakjoon Lee(1), Sanghoon Lee(1), X. Liu(2), and J. K. Furdyna(2)
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Hall effect and magnetization measurements were used to investigate the magnetic anisotropy of a ferromagnetic GaMnAs film grown on a (001) GaAs substrate. The Hall effect was systematically measured by applying an external field within the film plane. The switching behavior of the magnetization during the reversal process revealed the coexistence of in-plane and out-of-plane magnetic anisotropies. The out-of-plane anisotropy was dominant in the low-temperature region (i.e., 3–10 K), whereas the in-plane anisotropy became dominant in the temperature region higher than 15 K. This temperature dependent change in the magnetic anisotropy was further confirmed using direct magnetization measurements.

Mo-P-16

Structural properties of Co_2TiSi films on GaAs(001)

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Co_2TiSi films were grown by molecular beam epitaxy (MBE) on GaAs(001) and analyzed using reflection high energy electron diffraction, scanning- and transmission electron microscopy (SEM and TEM). In addition X-ray diffraction was combined with lattice parameter calculations by density functional theory (DFT) comparing the *L21* and *B2* structures and considering the influence of stoichiometry. Columnar growth is found as a result of a tendency towards phase separation driven by epitaxial misfit. The [Co]/[Ti]-ratio measured by electron energy loss spectroscopy (EELS) and energy-dispersive X-ray spectroscopy (EDX) is changing in dependence of the position in the film causing local disorder. The columnar structure is leading to anisotropic *B2*-ordering with the superior order parallel to the axes of the columns.

MBE fundamentals

Mo-P-17

Suppression of Twin Generation in the Growth of GaAs on Ge (111) Substrates

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Twin generation in the MBE growth of GaAs, GaSbAs, and GaAs on Ge (111) vicinal substrates has been characterized by X-ray diffraction. It has been shown that rotational twins are generated in the growth of GaSbAs with low Sb contents as well as in the growth of GaAs while they are not generated in the growth of GaSbAs with high Sb contents as well as in the growth of GaSb. Furthermore, it has been demonstrated that the generation of twin domains in GaAs can be suppressed by inserting GaSb as the buffer layer.

Mo-P-18

Scanning tunneling microscopy investigation of GaP MBE growth on nominal and vicinal Si(001) substrates for optoelectronic applications

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We present a detailed scanning tunneling microscopy (STM) study of GaP(001) MBE growth on nominal and vicinal Si(001) substrates. Antiphase domains and antiphase boundaries (APBs) are observed with atomic resolution. APBs annihilation is promoted on vicinal substrates. The use of Si(001) vicinal substrates also induces major modification of the growth front morphology (roughness, antiphase domain size and shape, terminal facets) from the early deposition stages, up to thick GaP layers. This study gives new and valuable hints on APBs annihilation mechanisms.

Mo-P-19

Effect of Kinetic Growth Parameters on Ga Surface Diffusion during MBE of GaAs

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The surface diffusion of Ga adatoms during GaAs MBE growth is studied by Monte Carlo simulations. The developed algorithm allows obtaining the growth rate and As_4/Ga flux ratio dependences of Ga diffusion characteristics. Ga diffusion length becomes smaller with increasing both growth rate and As_4/Ga flux ratio. This is attributed to the decrease in the lifetime of adatoms due to the intensive incorporation and leads to the increase in the island density. The As_4/Ga flux ratio dependences of Ga diffusion length and diffusion coefficient are stronger at a small growth rate whereas it is nearly the same for the lifetime.

Mo-P-20

Undoped 2D Electron Systems as a Tool for Optimizing MBE Growth

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The absence of remote ionized dopants in undoped GaAs/AlGaAs heterostructures allows the formation of low disorder 2D electron systems (2DESs), where mobility is dominated by unintentional background impurities and interface roughness. Measurement and modelling of the electron mobility in these systems can be used to determine the density of background impurities and the length and height scales of the interface roughness. We report the use of undoped 2DESs to quantify the effects on wafer quality of various MBE growth parameters, including As species, As overpressure, temperature and growth rate.

MBE fundamentals

Mo-P-21

GaAs-InAs-GaAs nanowires grown on Si substrates for single photon sources on Si.

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We present the growth of axial GaAs-InAs-GaAs nanowire heterostructures on Si(111), with the goal of integrating optically active InAs quantum dot on Si. Two different interfaces (InAs-on-GaAs and GaAs-on-InAs) were grown by Au-assisted molecular-beam epitaxy and studied by varying the growth parameters. We investigated structures by scanning electron microscopy, transmission electron microscopy and energy dispersive X-ray spectroscopy.

Mo-P-22

Behavior of Ga atoms deposited on GaAs (111)B surface

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We investigate behavior of Ga atoms deposited on GaAs (111)B surface by the intensity measurement of the specular spot of the reflection high-energy electron diffraction. We reveal that the deposited Ga atoms fill the Ga vacancy of √19 x √19 surface reconstruction untile the surface is fully covered by one mono-layer of Ga. Excess atoms deposited on the fully covered surface form droplets. They act as Ga source during As supplyand thus layer by layer growth occurs. Stable Ga coverage enables migration-enhanced epitaxy on (111) B surface.

Mo-P-23

Uniformity of local droplet etching across a wafer

V. Pasquali, F. le Mardelé, P. Atkinson

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Quantum dot formation via infilling of droplet-etched nanoholes is an attractive alternative to the Stranski-Krastanov dot growth mode, since it offers both independent control over dot density and dot size, and because droplet formation, which occurs via the Volmer-Weber growth mode, is, under certain conditions, less sensitive to small changes in deposition amount or substrate temperature. We study here the effect of different growth conditions on droplet formation and etching and compare the resulting homogeneity of the quantum dot ensemble across a whole wafer with that of a quantum well grown under the same conditions.

Mo-P-24

Optimized Substrate Offcut Angles for the Suppression of Hillocks on the MBE Grown AlSb Layers on GaAs Substrate

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We report on the influence of the offcut angle of GaAs (001) substrates on the AlSb metamorphic buffer morphology. The interaction of spiral steps winding around threading dislocations with the offcut- induced step flow results in a gradual change in morphology from one dominated by hillocks to that exhibiting near-parallel steps, upon increasing the offcut angle from 0 to 1°. Further increase in the offcut angle results in degradation of the surface morphology through emergence of progressively larger surface depressions. We propose a model, based on BCF theory, explaining the observed trends.

MBE fundamentals

Mo-P-25

Growth and characterization of unstrained GaAs valley-mount structures

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We use a combined approach of Ga assisted deoxidation, local hole etching and overgrowth to fabricate strain free GaAs valley-mount structures. An initial template of a Ga etched holes with an elongated GaAs mount is produced and then successively filled with AlGaAs and GaAs. Depending on the deposited amount of GaAs, the mount structure is up to 1 µm long and ca. 200 nm wide. Finally, we cap the structure with a top AlGaAs/GaAs layer to investigate optical properties. We find a good photoluminescence response from GaAs valley-mount structure up to room temperature forming their own class of mesoscopic structures.

Mo-P-26

Stacking InAs Quantum Dots over ErAs semimetal nanoparticles on GaAs(001) using molecular beam epitaxy

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We have been studying the epitaxial growth of ErAsmetal nanoparticles (MNP) in conjunction with InAs quantum dot (QD) for the purpose of producing all epitaxial MNP-QD hybrids which can elicit an enhanced optical response. Many critical parameters exist in the formation of these hybrid structures. Some are related to the MNP or QD shapes but two are related to the geometry of the MNP-QD hybrid. One is the separation between the MNP and the QD and the other is the orientation of the MNP relative to the QD. In this work, we study the growth of InAs QDs separated from an ErAs MNP layer by a GaAs spacer layer. We have varied the thickness of the GaAs spacer layer after the ErAs MNP growth from 4-20nm. We found the QDs can be aligned to underlying MNPs by careful control of the InAs growth conditions then assess the vertical alignment and separation.

Nanostructures (QDs, nanowires,..)

Mo-P-27

Detailed study of the influence of InGaAs matrix on the strain reduction in the InAs dot-in-well structure

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InAs/InGaAs dot-in-well structures have been investigated with the InGaAs thickness systematically varied. Both the strained buffer layer (SBL) below the dot layer and the strain reducing layer (SRL) above the dot layer were found to be responsible for the red-shift in photoluminescence emission of the InAs/InGaAs DWELL structure. A linear followed by saturation behavior of the emission red-shift was observed as a function of the SBL and SRL thickness respectively. Finite element analysis simulation and transmission electron microscopy measurement were carried out to analyze the strain distribution in the InAs QD and the InGaAs SBL.

Mo-P-28

MBE formation of GaAs nanostructures using nanosized ZnO films

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The nanosized ZnO films effect on the surface morphology of the GaAs epitaxial layer was studied with taking into account the main growth parameters of MBE technique: substrate temperature, effective As_4/Ga flux ratio, growth rate and thickness of ZnO films. The MBE modes of polycrystalline GaAs and GaAs nanowires formation were determined.

MBE fundamentals

Mo-P-29

The formation of indium based nanostructures by droplet epitaxy

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The MBE formation of In based nanostructures by droplet epitaxy technique was studied with taking into account the main growth parameters of MBE technology: substrate temperature and effective growth rate and thickness. The formation of two types of nanostructures was found: droplets – at low temperatures (300-350°C), and ring-shaped structures – at high temperatures (over 400°C).

Mo-P-30

Effect of GaAs native oxide on the Ga droplets formation during GaAs MBE growth

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The GaAs native oxide effect on the surface morphology of the GaAs epitaxial layer is studied with taking into account the main growth parameters of MBE technology: substrate temperature, effective As_4/Ga flux ratio and growth rate. The MBE modes of atomic smooth and rough surfaces and surfaces with Ga droplet arrays formation were determined. The mechanism of the influence of the interaction in the system "native oxide/substrate/growth component" on the surface morphology evolution during GaAs MBE was proposed on the basis of the experimental results.

MBE fundamentals

Mo-P-31

The Choice of As_2 vs. As_4 Species and its Influence on the Ripening of InAs/GaAs Quantum Dots

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A quantitative study of the consequences of growing InAs/GaAs Quantum Dots (QDs) by MBE using either As_2 or As_4 species has been carried out. Using an in-situ technique based on Reflection High-Energy Electron Diffraction (RHEED) and refined modeling of QD development it will be shown that practical understanding into the similarities and differences between the As species can be gained, as well as insight into the role of the Wetting Layer (WL) in the ripening of the dots.

Mo-P-32

Some aspects to the understanding of the droplet epitaxial nano-structure formation

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In this work, we are dealing with the understanding of the fundamental processes of the droplet epitaxy. For the reproducible preparation, it is very important to understand how the droplet epitaxial nano-structures form. The formation of these nano-structure such as quantum dots, quantum rings, nano-holes etc. is based on few basic processes. Here, one of the highlighted topic is the transition from liquid phase to solid phase. Another focal point is the solid to liquid phase transition. The investigated material system is GaAs and related semiconductor compounds.

Wide Bandgap semiconductors

Mo-P-33

Growth and characterization of $Al_yGa_{1-y}N$ based quantum dots for UV emission

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$Al_xGa_{1-x}N$ based heterostructures are seen as the base of the next technology for UV emitting devices. Our objective is to study the impact of the molecular beam epitaxy growth conditions on the $Al_yGa_{1-y}N$ quantum dots (QDs) structural and optical properties in order to fabricate samples with high QD densities emitting in the UV range. In particular, we investigate the impact of the QD deposited amount and composition as well as their $Al_xGa_{1-x}N$ matrix composition on the QD characteristics and their photoluminescence emission.

Mo-P-34

Growth and Characterization of High Indium-Content MBE-Grown InGaN Solar Cells

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p-GaN/*i*-$In_xGa_{1-x}N$/*n*-GaN double heterojunction solar cells grown by plasma-assisted molecular beam epitaxy are characterized. Four samples were grown with Indium compositions from 0.10<*x*<0.22 and absorbing *i*-$In_xGa_{1-x}N$ layer thicknesses from 35 to 192 nm. These parameters result in both non-relaxed and relaxed films, providing insight on the role of dislocation density on solar cell performance. Open circuit voltages as high as 1.5 volts were achieved under concentration and up to 0.96 V under 1-sun with photo response extending to wavelengths up to 500 nm. To our knowledge, the solar cells with *x*=0.22 represent the highest reported indium-content cells to demonstrate a photovoltaic response.

Mo-P-35

Progress Towards $In_xGa_{1-x}N$ Templates for Optoelectronic Devices

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Growth of $In_xGa_{1-x}N$ films with 0.15<*x*<0.50 and with thicknesses >1 µm grown at rates exceeding 2 µm/hour are demonstrated with plasma-assisted molecular beam epitaxy. Various buffer layer strategies were employed in an effort to facilitate a greater degree of relaxation in the $In_xGa_{1-x}N$ films relative to similar films grown directly on GaN templates without buffer layers. Such buffer layers resulted in fully-relaxed films, which could result in lower threading dislocation densities as growth is continued. Additionally,$In_{0.25}Ga_{0.75}N$/InN superlattice structures with an average indium content of *x*=0.32 are explored with promising smoothness, relaxation and x-ray diffraction figures of merit.

Mo-P-36

Properties of Self Catalytic and Patterned GaN Nanowires with $Sc_xGa_{1-x}N$ Insertion

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ScGaN nanowires are expected to combine the unique properties of the nanowire geometry with the advantages of the novel ScGaN materials system. GaN nanowires were grown by a self-catalytic method using MBE and a 20 nm $Sc_xGa_{1-x}N$ layer was inserted during growth. Scanning electron microscope-cathodo luminescence produced an emission at 3.26 eV which was not present in a control sample of GaN nanowires without any insertion. The bandgap of $Sc_xGa_{1-x}N$ depends on the x value which was found to be 0.04 ± 0.005. Growth of similar nanowires on patterned substrates will also be discussed, and comparisons drawn between the methods.

Wide Bandgap semiconductors

Mo-P-37

Surface Emitting Light Enhancement in Selective Area Grown GaN Nanowire Arrays on Si(111)

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Selective-area growth of high-density (2.5×10^9 cm^{-2}) GaN nanowires on Si(111) substrate by plasma-assisted molecular beam epitaxy is studied. Thin (30 nm) AlN nanopedestals used as nanowires growth seeds are fabricated by nano imprint lithography. GaN nanowires with hexagonal cross-section show the best optical quality with a strong resonant emission at 3.457 eV due to the light diffraction in two-dimension square nanowire array.

Mo-P-38

Achieving High n-type Carrier Concentration by Doping AlN Films with Si while Retaining the Structural Properties

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We have investigated the effect of Si doping on the structural, morphological and electrical properties of AlN films. One undoped AlN sample was grown, and two doped samples with different Si cell temperatures (1150°C and 1200°C) were grown. It has been observed that the crystalline structure of doped samples can be regained upon annealing and the surface properties suggest that the doped samples are as smooth as the undoped. The electrical properties obtained from Hall measurement show a carrier concentration as high as $8x10^{18}$ cm^{-3} which is stable upon annealing.

Mo-P-39

Growth mechanism of tapered InGaN/GaN nanorods with N-polarity on patterned Si(111) substrate

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We have investigated the growth mechanism of GaN and InGaN/GaN nanorods (NRs) with N-polarity on patterned Si(111) substrate. GaN and InGaN/GaN NRs with step- and tapered-shapes, respectively, were grown by varying the growth conditions, namely growth temperature and N_2 power. The shape evolution was explained based on the interrelation between Ga adatom diffusion along sidewall and local III-N ratio. Photoluminescence measurements showed that light intensity of tapered InGaN NRs is stronger than that of non-tapered InGaN NRs. Our results indicated that the fabrication of dot-in-NRs with tapered structure will be a promising approach for realization of high efficiency nano-scaled devices.

Mo-P-40

Study of the structural and optical properties of heavily Si-doped GaN

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We have studied the growth of heavily doped GaN films with Silicon by MBE. An improvement in optical and structural properties was found in heavily Si doped GaN layers grown on Si(111) substrates. An enhancement in the crystalline structure quality, evidenced by a reduction of dislocation density revealed by TEM and X-ray data analysis, as well as a decrease in the yellow band, measured by Photoluminescence, were observed when silicon doping concentration was increased from 3.2×10^{18} to 1.3×10^{20} atoms/cm^3. The characterization of the samples was carried out using SIMS, X-ray diffraction, STEM, Photoluminescence and Hall Effect.

Wide Bandgap semiconductors

Mo-P-41

Impact of GaN low-temperature buffer layer on GaN growth on Al templates

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GaN growth on metal templates has been expected for the application to light-emitting diodes (LEDs) with chemical liftoff processes. We have been proposed GaN growth on Al templates. The GaN layers on sapphire substrates with Al templates could be moved to Si substrates with chemical liftoff processes. However, surface cracks in their GaN layers were observed. Their reduction is a crucial issue for the application. In this paper, some approaches concerning with the reduction of cracks are reported. In particular, impact of GaN low-temperature (LT) buffer layer on the GaN is discussed.

Group-IV semiconductors

Mo-P-42

Tuning the magnetic properties of Mn_5Ge_3 by C doping: how to design a new material for spintronics application

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The Mn_5Ge_3 compound meets all the requirements for spin-polarized transport and injection into Ge. We have studied the structural and magnetic properties of $Mn_5Ge_3C_x$ films grown on Ge(111) by molecular beam epitaxy as a function of C concentration. Besides the compressive strain induced by the incorporation of C, the latter modifies significantly the Mn5Ge3 magnetic properties. While the Curie temperature increases from 296K to 450K as x is increased from 0 to 0.7, the magnetocrystalline anisotropy in C-doped samples is reduced by nearly one order of magnitude. This effect is assigned to hybridization between MnII and C atoms.

Mo-P-43

Microstructures and Photoluminescence Properties of GeSn/Ge MQWs and GeSn Film on Ge (001)

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$Ge_{1-x}Sn_x$/Ge MQWs and $Ge_{1-x}Sn_x$ film samples were grown on Ge (001). The Sn concentration and the strain in the GeSn layers were characterized by XRD mappings. Both samples show PL peaks at the same energy of 0.62 eV. Although the total thickness of GeSn layers in the MQWs (40nm) is much smaller than that of the film sample (200 nm), the PL intensities of the two samples are very close. It means that the optical properties of the GeSn/Ge MQWs are better than that of the GeSn film, which is explained in terms of crystal quality and quantum confinement effect

Mo-P-44

MBE grown Si nanocrystals on pit-patterned (001)Si

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Using large scale pre-patterned substrates, we fabricate by molecular beam homoepitaxy site- controlled, ordered arrays of Si-based nanocrystal pyramids on (001)Si wafers. Here we analyze some of the processes involved, focusing on two main aspects: island formation and island arrangement at or around the patterned pits. A combination of chemical, morphological and crystal structure analysis techniques is used in the investigation.

Group-IV semiconductors

Mo-P-45

Light Emission Enhancementfrom Ge Quantum Dots with Phosphorous δ Doping

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It is found that the room temperature PL intensity from Gequantum dots (QDs) can be enhanced by the Phosphorous $\boldsymbol{\delta}$ doping at Ge QDs/Si interfaces since stronger confinements of electrons at the interfaces can be realized by the doping. On the other hand, the high density doping modifies the dot formation kinetics and influences the light emission.It is, therefore, concluded that higher efficiency light emitting devices can be realized based on Ge QDswith optimaln-type doping and growth conditions.

Group-IV semiconductors

Mo-P-46

Evolution and engineering of the self-assembled Ge quantum dots onSi nano-pillars

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We systematicallyinvestigate the fabrication and the morphology evolution of precisely controlled Genanostructures on an array of ordered Si nano-pillars. By optimizing growth conditions during molecular beam epitaxy, different Ge nanostructures including quantum dot (QD) necklace, QD molecule and quantum ring are achieved at the pillar periphery. The inherent mechanism based on the anisotropic diffusion of adatoms and the strain relaxation on the pillar is proposed. Our results open a door to the controllable growth of QNs on the pillar, which facilitates the strong light-matter interaction.

Mo-P-47

Disorder-induced Relaxation of Optical Selection Rule in GeSn Photodetector Grown by Molecular Beam Epitaxy

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Response of $Ge_{0.975}Sn_{0.025}$ photodetector was investigated. The inter-band absorption is assigned to indirect transition; however, the absorption coefficient is two orders of magnitude higher than that of pure Ge. Consistent results were achieved by different research groups. We suggest the enhancement of absorption is attributed to relaxation of momentum conservation induced by random incorporation of Sn.

Mo-P-48

MBE of Tensile-Strained Ge Quantum Dots for Light Sources on Si

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MBE of tensile-strained Ge quantum dots (QDs) on different substrates is studied.The formation and evolution of the Ge QDs are investigated by RHEED, AFM and TEM. It is found that the growth on InAlAs/InP, InGaAs/InP and InAs/GaSb follows the Volmer-Weber (V-W) mode, while on GaSb/GaSb the Stranski-Krastanov (S-K) mode. The growth mode depends on both lattice mismatch and surface energy. The V-W mode is essential to avoid the wetting layer and the subsequent antiphase-domain defects when the QDs are capped with another III-V layer. Optical and other properties are under investigation with the aim for constructing light sources with tensile-strained Ge QDs for Si-photonics.

Nanostructures (QDs, nanowires,..)

Mo-P-49

Diameter Distributions in Self-Stabilized Growth of Ga-Catalyzed GaAs Nanowires

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In this work we report on evolution of the radius distribution of the vertical Ga-catalyzed GaAs nanowires which are fabricated via the vapor-liquid-solid mechanism. Both full model and approximation of regular growth and fluctuation coefficient equality model are analyzed depending on the III/V flux ratio. Obtained analytical solutions of these models describe both infinite growth which corresponds to Poissonian broadening and self-equilibration of the radius distribution of the self-catalyzed GaAs nanowires. Numerical calculations which are obtained by solving the Fokker-Planck equation by the implicit difference scheme are also presented.

Mo-P-50

Photoluminescence around 2μm wavelength region from InAs quantum dots embedded by strain-reducing layer on InP substrate

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InAs quantum dot (QD) grown on InP(001) vicinal substrates was capped by an InGaAs strain reducing layer (SRL) to increase the emission wavelength. The size and density of QDs showed same properties with and without SRL, so that high-density InAs QDs were obtained even if the SRL was introduced. The peak wavelength of QDs photoluminescence changed from 1600nm, in conventional structures, to 2000nm measured at room temperature.

Mo-P-51

Self-Catalyzed High-Quality GaAsP NWs on Silicon and their Application in Photovoltaics

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Growth of self-catalyzed high-quality core-shell GaAsP nanowires (NWs) has been achieved on both patterned and un-patterned Si substrates by solid-source molecular beam epitaxy. The NWs are highly uniform in morphology with almost stacking fault free zinc blend crystal structure. Their potential application on photovoltaic has been demonstrated by single NW solar cells with a high efficiency exceeding 10% and water splitting devices with a wafer-scale solar-to-hydrogen conversion efficiency of 0.5%. Moreover, the growth of defect-free dot-in-wire structure was also achieved. Without any surface protection layer, an exciton emission line width as narrow as 130μeV has been observed. Those results not only provide valuable information in the high-quality NW growth, but also show the perspective for achieving high-efficiency low cost photovoltaic devices.

Mo-P-52

Epitaxial Superconducting Al on InSb Nanowires and Networks

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Newly proposed hybrid systems of semiconducting wires with mesoscopic superconducting (SC) islands have become attractive for a number of applications in the readout of Majorana zero modes. In this work, we investigate the growth mechanism and properties of epitaxial aluminum (Al) grown on InSb nanowires (NWs) and nanowire networks. We show a high-quality epitaxial interface between an InSb NW and a superconducting Al after in-situ treating the wires with the atomic hydrogen.

Nanostructures (QDs, nanowires,..)

Mo-P-53

Strain and Anisotropy Effects Studied in InAs/GaAs(221) Quantum Dashes by Raman Spectroscopy

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Quantum dashes were synthesized in the molecular beam epitaxial growth of InAs on GaAs(221). Polarized Raman spectroscopy was utilized in order to characterize the samples and to evaluate both, the strain status near surface and the surface anisotropy imposed by the quasi one-dimensional character of the quantum dashes. The spectra showed deviation from the selection rules caused by the surface anisotropy of the samples. The longitudinal and transversal optical phonons intensity ratio slightly changes with the arsenic pressure, but strongly depends on the orientation of the quantum dashes relative to the polarized direction of the Raman laser excitation source.

Mo-P-54

GaAs nanowires with oxidation-proof arsenic capping for the growth of heteroepitaxial shell

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Self-catalyzed GaAs nanowires (NWs) have been fabricated by VLS-MBE to perform heterogeneous core/shell NWs. For protecting the active surface of GaAs core and achieving epitaxial core/shell NWs with better physical performances, a reversible arsenic (As)capping-decapping method is used. The surface oxidation of GaAs core is fatal on the AlGaAs shell epitaxial growth, while the capping-decapping method can realize the epitaxial core/shell heterostructure. This simple method will allow the growth of the heterogeneous shell, such as functional oxides, on III-V semiconductor NWs. Thereby, GaAs(core)/$SrTiO_3$(shell) NWs were then fabricated. Partially epitaxial shell is obtained thanks to the capping-decapping method.

Mo-P-55

Flat top formation in self-assisted GaAs nanowires

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The transformation of the Ga droplet into a nanowire segments with a flat top surface parallel to the substrates in self-assisted nanowire growth was achieved through an accurate control As flux and substrate temperature during annealing. We found that a sizeable adatom diffusion of As absorbed on the nanowire side facets to the top is present at intermediate temperatures. Such additional As flux, plays a fundamental role in determining the top nanowire morphology.

Mo-P-56

Nanostructured Surfaces for Teraherz Generation

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We present a fully self-assembly technique, based on Droplet Epitaxy, to fabricate semiconductor surfaces functionalized with asymmetric planar quantum dot molecules –metal nanoparticles hybrid systems for efficient THz generation. The role of growth parameters on molecule fabrication and metal nanoparticle alignment for the matching of the grown system with the design requirements is discussed.

MBE fundamentals

Mo-P-57

InSb Quantum Nanostructure on Cross Hatched Substrate

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Attempt to realize ordered InSb nanostructures on cross hatched substrate is reported. The structure is grown in a solid-source molecular beam epitaxy. GaAs cross hatched pattern is first realized by the growth of 30-nm thick InGaAs and then 6-nm GaAs layers. Cross hatched pattern aligned along [110] and [1-10] are clearly observed by atomic force microscopy. Self-assembled InSb nanostructures, which have rectangular base, are then grown on this cross hatched pattern. Partial ordering of InSb nanostructure is observed on the pattern aligned along [1-10]. Raman spectroscopy is used to probe the residual strain in the GaAs cross hatched pattern.

Nanostructures (QDs, nanowires,..)

Mo-P-58

Molecular Beam Epitaxy Growth of InSb/GaAs Quantum Nanostructures

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InSb/GaAs nanostructures grown by solid-source molecular beam epitaxy are investigated in this work. Rectangular-based InSb nanostructures are obtained by self-assembled growth at relatively low growth temperature with low InSb growth rate of 0.008 monolayer/s. Elongation of nanostructure base is along [110] direction. Facet analysis of the free-standing InSb nanostructure shows that each nanostructure has flat top (001) surface while side facets are along [1-1n] direction. Raman spectroscopy reveals both InSb-related peaks at 181 and 189 cm^{-1} and GaAs-related peaks at 268 and 293cm^{-1}. Raman spectroscopy with different excitation wavelengths is applied to probe residual strain in subsurface GaAs layer.

Mo-P-59

Structural and Magnetic Properties of MnAs Nanocrystals Embedded in (In,Ga)As Semiconductor Nanowire Shells

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We have investigated core shell (In,Ga)As-GaAs:MnAs nanowires (NWs) with magnetic MnAs nanocrystals embedded in thin GaAs nanowire shells. The (In,Ga)As NW cores were grown by MBE using Au-catalyst predeposited on GaAs(111)B substrates; the shells containing MnAs nanocrystals were obtained by high temperature annealing of core-shell NW structures with (Ga,Mn)As shells deposited on primary (In,Ga)As core NWs. The properties of MnAs nanocrystals, such as densities, dimensions crystallographic structure can be controlled by choosing the thickness and appropriate Mn content in primary (non-annealed) GaMnAs shells, and by the details of high temperature post-growth annealing procedure.

Mo-P-60

A Modified Gradient Approach for the Growth of Low-Density InAs Quantum Dot Molecules by Molecular Beam Epitaxy

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InAs quantum dot molecules, i. e., two vertically stacked InAs quantum dots separated by a thin GaAs barrier, have been prepared employing a modified gradient approach: For the growth of the first quantum dot layer, the substrate rotation was stopped and In was deposited with a gradient across the surface. This In gradient translated into a gradient in the quantum dot density for the bottom layer. For the second quantum dot layer, homogenous In deposition was employed. Despite the homogenous In deposition, we observe for a certain coverage range that the density gradient in the bottom layer is reproduced in the top layer.

Nanostructures (QDs, nanowires,..)

Mo-P-61

Growth of InN/GaN Dots on 4H-SiC(0001) 4° off Vicinal Substrates by Molecular Beam Epitaxy

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We have fabricated self-assembled InN dots on GaN using 4H-SiC(0001) vicinal substrates (4° off toward [11-20]). The size and density of InN dots were well controlled by changing the deposition amount of InN. Atomic force microscope (AFM) observation revealed that the critical thickness of InN for 2D-3D transition is between 1.0 and 1.2 nm. In addition, it was found that the InN dots were preferentially formed at the multistep edges on GaN. Therefore, the preparation of periodic multistep structures on GaN is considered to be an effective way to obtain highly ordered self-assembled InN dot arrays.

Nanostructures (QDs, nanowires,..)

Mo-P-62

Structural and optical properties investigation of (In,Ga)As/GaP quantum dots for direct bandgap emission

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Room temperature electroluminescence of a GaP-based LED on Si and photoluminescence of (In,Ga)As quantum dots (QDs) located at 200nm of the III-V/Si interface were obtained, illustrating the good structural quality of the GaP/Si template used. The last step towards room temperature lasing on Si is thus reaching the direct bandgap emission. In this work, we investigate the structural and optical properties of (In,Ga)As/GaP QDs, and show that it is possible to incorporate 35% of In with a high density of QDs, and discuss the results obtained in view of the direct bandgap emission.

Mo-P-63

Self-Catalyzed Growth of Strained GaAs/InGaAs Core-Shell Nanowires

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Strained GaAs/InGaAs core-shell nanowires are theoretically predicted to exhibit significant piezoelectric fields that can be exploited to efficiently separate and collect charge carriers in a photovoltaic device. In this work, we demonstrate the molecular beam epitaxy growth of GaAs/InGaAs core-shell nanowires on Si(111) substrate covered with a chemical oxide layer. The highly-vertical GaAs nanowires are grown in Ga-assisted vapour-liquid-solid (VLS) growth mode, while the InGaAs shells are grown in non-VLS mode. We investigate the optimal growth conditions for maximising growth selectivity and InGaAs compositional homogeneity.

Mo-P-64

Effects of Sb-soak on InAs Quantum Dots Grown on (001) and (113)B GaAs Substrates

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The effects of Sb-soak on quantum dots (QDs) grown on (001) and (113)B GaAs substrate were investigated. Surface morphologies of QDs were characterized by atomic force microscopy (AFM). The optical properties of QDs were measured by photoluminescence (PL). The density of (001) QDs increased clearly after Sb soak. However, the density of (113)B QDs almost remain unchanged. Blue-shift was observed for Sb-soaked (001) QDs compared with QDs without Sb-soak. On the other hand, red-shift was seen for Sb-Soaked (113)B QDs. The results showed that effects of Sb-Soak on QDs grown on (001) and (113)B GaAs substrate were quite different.

Nanostructures (QDs, nanowires,..)

Mo-P-65

Growth and Photoluminescence of InN Nanodots by Droplet Epitaxy

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In this report, InN nanodots are grown on the surface on Si (111) and Al_2O_3 (0001) substrates by droplet epitaxy, which is the formation of indium droplets in ultrahigh vacuum and then the nitridaiton by the radio frequency nitrogen plasma. During the growth, the surface conditions and InN nanodots are analyzed by the *in-situ* reflection high energy electron diffraction. The density of InN nanodts on Si can reach $2.9E^{10}$ cm^{-2}. Chemical composition and optical properties of InN nanodots are characterized by the measurements of X-ray photoelectron spectroscopy and photoluminescence.

Mo-P-66

Effect of substrate temperature on self-assisted GaAs nanowires grown by Molecular Beam Epitaxy on GaAs(111) substrates without SiO2 layer

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Semiconductor nanowires are considered one of the versatile nanoscale building blocks for the model of photonic and artificial photosynthesis devices. The first demonstration growth of nanowires has been realized by means of Au-catalyzed Vapor-Liquid-Solid growth in 1964. This technique leads to an unintentionally incorporation of Au atoms during the growth. In 2008, a technique of self-assisted growth with SiO_2 layer was proposed. This technique can overcome the contamination of catalyst but the process needs SiO_2 coating which is hard to control the optimal thickness of SiO_2 layer. Recently, a new technique of self-catalyst growth without SiO_2 was proposed. The steps of this method are droplet forming (as a catalyst) and nanowire growth. However, the information of growth conditions of this new growth mode are still limit. In this work, a systematic study on the effect of substrate temperature on self-assisted GaAs nanowire without SiO_2 layer grown by molecular beam epitaxy on GaAs(111) is investigated. Surface morphology, elemental composition, and crystal structure of GaAs nanowire samples were characterized by Scanning Electron Microscope (SEM), Energe-Dispersive X-ray spectroscopy (EDX), and X-ray diffraction, respectively.

MBE fundamentals

Mo-P-67

Crystal phase control of a MBE-grown III-V nanowire

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In this work we present a method for controlling the crystal structure of MBE grown III-V nanowire. The method is based on difference of formation energy for nucleation islands with different crystal structures. Results show that the crystal phase is dependent on the initial position of the nucleation island, hence there are preferred nucleation areas on the top facet of the nanowire, and that there is a critical chemical potential that determines the crystal phase.

Nanostructures (QDs, nanowires,..)

Mo-P-68

High-Intensity and Broadband Emission Centered at ~1 um from InGaAs 3D Nanostructures Formed by High-Temperature Molecular-Beam-Epitaxy Growth

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We report a high-intensity and broadband emission centered at ~1 μm that was obtained from an InGaAs thin layer grown on a GaAs substrate by molecular beam epitaxy at a high growth temperature. InGaAs/GaAs is normally grown below 450°C to avoid In segregation and desorption; however, we found a narrow window of growth temperatures above 500°C that yield high-intensity and broadband emission. The surface morphology of the InGaAs layers suggests that the emission resulted from the In(Ga)As 3D nanostructures formed on the substrate with large distributions of size and In composition. This offers a new nanomaterial for near-infrared broadband light sources.

Mo-P-69

Fabrication of high-quality strain relaxed SiGe(110) films by controlling defects via ion implantation

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It is found that the strain relaxation of the SiGe(110) film is largely enhanced by Si ion implantation into SiGe/Si heterostructures. Implantation-induced defects act as dislocation sources and enhance the strain relaxation. Moreover, a surface of the relaxed SiGe(110) is free from large surface roughness and steps caused by stacking faults generation. It is, therefore, expected that high-mobility strained Si/Ge channels can be formed on the SiGe(110) relaxed buffer layers. It is also demonstrated that the local introduction of the implantation defects allows controlling of lateral strain states and dislocation generation, opening new concepts of strain engineering.

Mo-P-70

Record (7.7%) of B incorporation into GaN by molecular beam epitaxy

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The full potential of III-nitride materials is hampered by the lack of suitable substrates. The lattice constant and thermal expansion coefficient mismatch usually leads to a high dislocation density, mosaic crystal structure, biaxial stress, and wafer bonding. Introduction of boron might be one of the possible solutions to mitigate the problems, compensating the strain induced by indium in InGaN or providing lattice matching for BGaN grown on AlN and SiC substrates. In this work, we report on record 7.7% of B incorporated into GaN-on-sapphire by molecular beam epitaxy.

Mo-P-71

Selective Area Growth of N-polar GaN Nanorods by Plasma-Assisted MBE on Micro-Cone-Shaped Patterned c-Sapphire Substrates

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The nanomask-free selective area growth of N-polar GaN nanorods (NR) was developed by plasma-assisted MBE (PA MBE) on micro-cone-shaped patterned c-sapphire substrates by using two-stage growth process. The GaN nucleation layer grown by migration enhanced epitaxy provides the best selectivity for nucleation of NR on the cone tips, while the standard high-temperature PA MBE at the nitrogen-rich conditions leads to growing the 1-μm-long NRs with a constant diameter of about 100 nm. We demonstrate a relatively bright and narrow μ-photoluminescence peak at a wavelength of 450-500 nm, originating from an InGaN/GaN single quantum well inserted in the top of the individual site-controlled NR.

Mo-P-72

Growth Suppression by Metal Droplets of $In_{0.5}Ga_{0.5}N$/Si(111) at Low Temperatures

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We investigate the effect of surface Ga accumulation on the growth of $In_{0.5}Ga_{0.5}N$ by PAMBE at low temperatures (T= 440 °C). We find that the control of the surface metal condition is very important because the crystallization process strongly depends on the metal flux impinging on the surface. The growth rate rapidly decreases when the supply of metal flux exceeds certain amount. Such phenomenon can be explained by the model taking into account droplet effects on the incorporation of metals adatom into the crystal.

Mo-P-73

Nano-Structural Characterization of Cubic InN Dots Grown on Single-Domain Cubic GaN by Transmission Electron Microscopy

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Nano-structural characterization of self-assembled c-InN dot arrays formed on a single-domain c-GaN layer was carried out by means of transmission electron microscopy (TEM). The sample was grown on a MgO(001) vicinal substrate (3.5° off toward [110]). It is found that the alignment nature of the c-InN dots arises from straight steps generated by stacking faults in c-GaN. A high-resolution scanning TEM image revealed atomic configuration of Ga and N in the c-GaN layer. The crystalline direction of the single-domain c-GaN layer was determined as $[110]_{c\text{-}GaN}$ is parallel to the vicinal direction of the substrate, i.e. $[110]_{MgO}$.

III-V compounds

Tu-P-1

Growth of GaPand AlGaP on (111)GaP using Gas-Source Molecular-Beam-Epitaxy

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We discuss the influence of the growth parameters on the surface morphology and the interface quality of the homoepitaxial GaP(111) and heteroepitaxial GaP/AlGaP(111) structures grown using GS-MBE. The RHEED patterns show several surface reconstructions during growth of GaP.The GaP layers have roughsurface (rms about 3-10 nm). The surface roughness may be related to the unstable surface reconstructions. The TEM Investigations of the GaP/AlGaP structures reveal ahigh density of stacking faults and twins in the AlGaP layer and a smooth interface between AlGaP/GaP. Further analysis by XRD confirms the existence of twins in the GaP/AlGaP structures.

Tu-P-2

Effect of Low Temperature Growth and a Distributed Bragg Reflector on the emission from Molecular Beam Epitaxy-Grown Er δ-doped GaAs

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We have investigated the effect of low temperature growth and a distributed Bragg reflector (DBR) on the emission from Er δ-doped GaAs grown by molecular beam epitaxy. Several samples were grown with varying low temperature GaAs overlayer thickness to control the Er area density. The areal density of Er atoms was estimated from the fluctuation of Er luminescence intensity. We found the lowest area density was 16 atoms/μm^2. We have also grown Er δ-doped GaAs with DBR to enhance the Er emission intensity. The emission from Er δ-doped GaAS with DBR was approximately 7 times stronger than that without DBR.

Tu-P-3

Epitaxial Growth and Characterization of Cubic $In_xGa_{1-x}N$/GaN quantum wells on GaAs(001) Substrates

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Cubic $In_xGa_{1-x}N$/GaN quantum wells (QWs) with x≈0.2 and x≈0.27 exhibiting green photoluminescence at room temperature were achieved by RF-MBE. The QWs were grown on GaAs(001) substrates at different temperatures ranging from 600 to 680 °C. We found that, by increasing the growth temperature above 600°C, the In content (x) decreases due to desorption from the growing surface. This is another method to vary in a controlled the In content of c- $In_xGa_{1-x}N$ QWs. The green emission of QWs does not show up any red-shift, when the excitation power is increased, which may be useful to increase the efficiency of cubic nitride based devices.

Tu-P-4

Strain-free quantum dots embedded in a two-dimensional electron gas

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We present here the use of in-situ droplet etching to locally modify the thickness of a modulation doped quantum well, to create quantum dots embedded in a two-dimensional electron gas. The effect of these strain-free quantum dots on the 2DEG mobility will be discussed.

III-V compounds

Tu-P-5

Growth and Characterization of AlInAsSb layers lattice-matched to GaSb

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AlInAsSb is a promising material for opto-electronic applications: it can be lattice-matched to GaSb, InP or InAs and coversa wide range of band gap energies. However, its significant miscibility gap is an obstacle to its production by near-equilibrium growth techniques and experimental studies are scarce. We have grown AlInAsSb layers on GaSb substrates by MBE. Stable materials with Al content ranging from 0.25 to 0.70 demonstrated photoluminescence emission. Post-growth annealing resulted in a band gap shift towards higher energy, correspondingly to the parameters estimated in the literature.

Tu-P-6

High Electron Mobility, Photoluminescence and the Ga Quality in GaAs/AlGaAsbased 2D Electron Gases

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The role of the purity of Ga for the growth of GaAs/AlGaAs heterostructures has been puzzling. Ga lots with the seemingly highest possible purity have led to electron mobilities of 2d electron structures which were rather poor while other ones performed excellently. In this contribution we report on our comparison of electron mobility and photoluminescence spectra of heterostructures grown over several years in four different MBE systems and find in most cases a close correlation between the two measurements. We also note that a "bad" Ga leads to a dramatic reduction of the free excitonluminescence which might be useful as an early indicator of the Ga quality.

Tu-P-7

Improving InSb Quantum Well Properties towards Majorana Physics Applications

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Due to its large g-factor, InSb is one of the prime candidates when it comes to Majorana physics. In order to provide the fundamental platform for large-scale Majorana networks, the step towards two dimensional, high quality InSb heterostructures is evident. We investigate the influence of several relaxed buffer structures and characteristic parameters on the InSb quantum well performance. This allows us to grow quantum wells with mobilities of up to 342 000 cm^2/Vs and well-pronounced quantum transport features by using molecular beam epitaxy.

Tu-P-8

InGaAs/GaAsSbsuperlattice photodiodes with P-type compensation-doped absorption regions

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Effects of p-type compensation doping are studied on quantum efficiency (QE) and dark currents of InGaAs/GaAsSb superlattice (SL) Short wavelength infrared photodiodes grown by molecular beam epitaxy on InP substrates. By optimizing the doping concentration in the absorption region, quantum efficiency as high as61.4% is achieved at a doping density of 7.5×10^{15} cm^3 while the dark current density is as low as 5.4×10^{-4} A/cm^2 at 20 °C.

III-V compounds

Tu-P-9

Up-converted photoluminescence in InAs/GaAs heterostructures

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Up-converted photoluminescence in InAs/GaAs heterostructures are investigated. In addition to the intermediate state responsible for up-conversion, relaxation process imposes another great challenge for efficient UPL. To overcome this problem, we propose InAs/GaAs heterostructures with different confined states. It is found that by introducing InAs/GaAs multi quantum well structure, efficient UPL is observable.

Tu-P-10

Growth, Transport and Structural Study of the AlSb/InAs Interface

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The semiconductor heterostructures based on the so-called 6.1 Å family (InAs, GaSb, AlSb) are of high interest for device applications and basic research. It has been established for a long time that the nature of the interfaces has a strong impact on the structural and transport properties. Here we present an extensive study on the structural (STEM, XSTM) and transport properties of GaSb/InAs or AlSb/InAs heterostructures depending on the interface growth sequence. In particular, we observe significant atom exchanges at the interfaces.

Tu-P-11

Effect of Nitridation Time on Structural, Optical and Electrical Properties of InN Films Grown on c-Spphire Substrates by PAMBE

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We have investigated the effect of nitridation time of the sapphire substrates on the structural, morphological, optical and electrical characteristics of the InN films grown on those sapphire substrates by plasma assisted molecular beam epitaxy technique. Two films were prepared with nitridation times of 1 hour and 2.5 hours respectively. Full width half maximum of ω-scans around x-ray diffraction peaks of symmetric and different asymmetric planes were drastically reduced by increased nitridation time, hence the threading dislocation densities were also reduced considerably. The atomic force microscopy also showed improvement in surface roughness. Interestingly, upon prolonged nitridation, a prominent blue shift in PL spectra was observed which had also been confirmed by infrared absorption spectroscopy. Electrical properties obtained from Raman spectra conform to PL results.

Tu-P-12

Fine tuning of *n*- and *p*-type doping of GaSb epitaxial layers

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We report on the control of both *n*-type and and *p*-type doping, particularly in the low-doping regions. We demonstrate electron mobility as high as ~8000 $cm^2.V^{-1}.s^{-1}$ for *n*-type layers with Nd-Na ~ 2 $x10^{16}$ cm^{-3} and hole mobility of ~750 $cm^2.V^{-1}.s^{-1}$ for not-intentionally doped layers with Na-Nd ~ 3 $x10^{16}$ cm^{-3}. We show that the *n*-type to *p*-type transition occurs within a temperature excursion of ±2 °C for the Te-dopant cell.

III-V compounds

Tu-P-13

Comparative Study of Initial Growth Stage of InN On Epitaxial Graphene by MBE and MOVPE

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InN isattractive material for various devices. However, until now, it is difficult to form p-type InN due to the highly residual back ground carriers induced by the high density of defects that caused by the interfacial stressin the InN layer on the conventional substrate like α-Al_2O_3. Van der Waals epitaxy is expected to overcome the problems by reducingthe interfacial stress.In this paper, we have investigated about theinitial growth stage of nitride semiconductoron the single domain epitaxial graphene by RF-MBEto obtain the high quality InN, accompanied with the comparative view points from MOVPE growth.

Tu-P-14

AlGaP-growth and doping by MBE

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Here, we study the growth of n- and p-doped AlGaP alloys on GaP substrate, in view of their use in laser devices. The impact of growth temperature and growth rate on structural and electrical properties is studied with atomic force microscopy, C(V), Hall effect measurements, SIMS analysis and deep level transient spectroscopy (DLTS). Typical structural defects are identified and characterized. As a main result, it is found that doping of the AlGaP is disabled when the growth temperature is not high enough. This is evidenced by DLTS measurements that reveal deep level trapping.

Tu-P-15

Correlation between dark currents and thermal activation energies of photoluminescence in InP- and GaAs-based $In_{0.83}Ga_{0.17}As$ photodetectors

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InP- and GaAs-based metamorphic $In_{0.83}Ga_{0.17}As$ photodetectors were grown and investigated. For the photodetectors with mesa diameter of 300 μm, the dark currents at -10 mV are 674 nA and 2.28 μA at 300 K, 3.99 pA and 2.17 nA at 77 K for InP- and GaAs-based photodetectors respectively. Correspondingly, the photoluminescence intensity of the $In0._{83}Ga_{0.17}As$ layer on GaAs is several times weaker than that on InP. The device performance correlated with the nonradiative recombination process in the absorber in two distinct temperature ranges.

Tu-P-16

Chances and Limitations of high-speed approaches to Reciprocal Space Mapping

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Recent advances in detector technology (PANalytical Galipix3D & PIXcel3D), positioning algorithms and signal processing allow now Reciprocal space maps (RSM) to be recorded in similar timescales as rocking curves with strong impact to the usability of this technique. These high-speed measurements find applications of the characterization in all crystalline advanced materials. Position sensitive detectors allow to collect many points at once and can be used in continuous mode, so less measurement and positioning steps are necessary to build up a given area of reciprocal space. This contribution will discuss chances and limitations.

III-V compounds

Tu-P-17

In content dependence on crystalline state of low-temperature-grown InGaAs

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We investigated crystalline state of low-temperature-grown (LTG) $In_xGa_{1-x}As$ on InP substrate grown by molecular beam epitaxy at substrate temperatures of 240-250˚C using X-ray diffraction (XRD) and Rutherford backscattering spectrometry (RBS). The RBS angular scan indicated that position of interstitial In atoms in LTG $In_xGa_{1-x}As$ does not change after annealing at 550 ˚C while XRD peak of $In_xGa_{1-x}As$ layer shift to higher angle, suggesting a possibility that other causes of this structural transformation induced by annealing above 550 ˚C excepting for interstitial In atoms.

Tu-P-18

Molecular beam epitaxy and characterization of $InAs_{1-x}Sb_x$ epilayers grown on GaAs (001) substrate

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We report on the molecular beam epitaxial growth and characterization of undoped and Be doped $InAs_{1-x}Sb_x$ layers grown on lattice mismatched semi-insulating GaAs (001) substrate with 2° offcut towards <110> with $0 < x < 0.71$. The electrical properties, crystalline quality and surface morphology were assessed by Hall measurement, X-ray diffraction, Nomarski microscopy and high-resolution optical profilometry, respectively. The influence of InAs buffer layer on the quality of InAsSb layers was also examined. In addition, the influence of the Sb/As flux ratio on the composition x was investigated.

MBE grown Devices

Tu-P-19

Surface modification of GaSb and InAsSb:Si by phosphonates for plasmonic applications

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Highly-doped semiconductor (HDSC), in particular Si doped InAsSb layers lattice matched to GaSb, allow to fabricate plasmonic nanostructures to perform surface-enhanced infrared absorption (SEIRA) spectroscopy. We present a new approach to modify the surface of III-V semiconductor devices using phosphonate coupling agents. Exploiting the native oxide, we expect under ambient condition a higher stability compared to thiol coupling agents. We could successfully demonstrate the binding of relevant molecules to MBE grown layers and address the question of stability in a current study.

III-V compounds

Tu-P-20

Optical spectroscopy analysis ofembedded layers in AlGaAs/GaAs heterostructures grown by MBE

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In this work the use of optical spectroscopies to evaluate the properties of the individual layers of AlGaAs/GaAs heterostructures is presented. Surface layer defects were evaluated by photoreflectance through the intensity of electric field produced by the surface states. Raman measurements were used to calculate the doping layer profile using the intensity ratio between the LO and L- phonon modes. The Al concentration in the AlGaAs layers was determined using the LO-AlAs like mode and Franz–Keldysh oscillations observed above the bandgap transition of the ternary alloy. The AlGaAs/GaAs interfaces were evaluated by the electric field strength of the 2DEG.

III-V compounds

Tu-P-21

Post growth strain relaxation of relaxed AlSb epilayers on GaSb and GaAs

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Temperature dependent X-ray diffraction measurements were performed on thick (2.8 microns) AlSb epilayers grown by molecular beam epitaxy (MBE) on GaSb and GaAs at different growth temperatures in order to characterize the post growth strain relaxation dependence on temperature and strain. The thermal expansion difference between AlSb and GaSb/GaAs is large enough to give easily measurable strains at room temperature when the AlSb layer relaxes at growth temperature. By changing the growth temperature and substrate it is possible to separate the effect of temperature and strain on the relaxation process.

Tu-P-22

Interface roughness scattering in $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}$ As double quantum wells grown on (100) and (411)A substrates at different growth temperatures

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We compare the interface roughness scattering of electrons at the $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ hetero interface grown on (100) and (411)A oriented substrates using gas-source molecular-beam epitaxy (MBE). A modulation-doped double quantum well structure (DWQ) is designed to emphasize the effects of interface scattering. The transport properties for both (100) and (411)A orientations are compared for different MBE growth temperatures. The highest mobilities on (411) oriented structures are 80% higher than those on (100) oriented structures, indicating less electron scattering due to interface roughness scattering. We also discuss device applications of the results.

III-V compounds

Tu-P-23

Two distinct intersubband transitions absorbing the same frequency in a three levels GaAs/AlGaAs quantum well with a specific geometry

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We are interested in a GaAs/AlGaAs quantum well with 38% of Aluminium with two allowed transitions E_{12} and E_{23}. When including the bands non parabolicity into the calculations, E_{12} and E_{23} transitions show a clear crossing for a specific geometry. This suggests the possible enhancement in the absorption if a radiation have the appropriate frequency such that $hv=E_{12}=E_{23}$. To quantify this phenomenon, we have calculated the absorption coefficient for two different geometries. As the E_3 level is close to the continuum in the specific geometry, the corresponding structure can be potentially used in two photons absorption devices.

Dilute Nitrides and Bismides

Tu-P-24

Light emission above 1.6 μm from InAs/GaAsBi grown by molecular beam epitaxy

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We have systematically studied initial capping of InAs quantum dots (QDs) by GaAsBi on GaAs substrates grown by molecular beam epitaxy. At the growth temperature of 500°C used for InAs QD growth, Bi acts as surfactant, while Bi is incorporated in GaAsBi when grown at 410°C. Without Bi, the photoluminescence emission wavelength decreases from 1.52 to 1.26 μm at room temperature when increasing GaAs cap layer from 1 to 32 monolayers. By capping GaAsBi, the corresponding emission wavelength increases from 1.63 to 1.66 μm when the GaAsBi cap layer thickness increases from 1 to 32 monolayers.

Tu-P-25

InAsBi quantum wells grown on InP-based metamorphic InAlAs buffers for mid-infrared applications

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InAsBi quantum wells have been grown on InP-based metamorphic $In_{0.8}Al_{0.2}As$ buffers. An $In_xAl_{1-x}As$ grading buffer was used to achieve a virtual substrate. The quantum wells were grown at around 330 °C and the quantum well thicknesses are nominally 15 nm. X-ray diffraction indicates the increased lattice constant of quantum well layer after bismuth incorporation. The samples show photoluminescence beyond 3 μm at room temperature, with is longer than the InAs quantum well reference sample. The results indicate the promising potential of InAsBi quantum wells for mid-infrared optoelectronic applications.

Tu-P-26

Optimizing the Opto-Electronic Properties of GaAsBi by Tuning Growth Conditions

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A systematic series of p-i-n diodes was grown by MBE to investigate the impact of growth conditions on the optical, structural and electronic properties of GaAsBi. The Bi contents of the samples show both growth temperature and Bi flux dependences. The samples grown at high temperatures show evidence of long range inhomogeneity; whereas, samples of comparable Bi content grown at lower temperatures appear to have well defined, uniform GaAsBi regions. The high growth temperature samples also exhibit the brightest PL from the series. The electrical characteristics of these samples are used to investigate the optimal growth conditions for opto-electronic devices.

Tu-P-27

Photoluminescence of InGaAs/GaAsBi/InGaAs type-II quantum well grown by gas source molecular beam epitaxy

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$In_{0.2}Ga_{0.8}As/GaAsBi_{0.04}/In_{0.2}Ga_{0.8}As$ quantum well (QW) were grown on GaAs substrates by gas source molecular beam epitaxy for realizing the type-II band-edge line-up. Both type-I and type-II transitions were observed in the Bi containing W QW. Blue-shift of type-II transitions at high excitation power density was observed and ascribed to the band-bending effect. The calculated transition energies based on 8 band *k·p* model fit well with the experiment results.

Dilute Nitrides and Bismides

Tu-P-28

GaAsBi/GaAs MQWs LED grown by MBE

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A p–i–n diode structure with eleven periods of highly strained $GaAs_{0.96}Bi_{0.04}/GaAs$ (12 nm / 12 nm) MQWs has been grown on a GaAs (100) substrate by MBE. We fabricated a light emitting diode with a stripe geometry metal contact and observed a single EL peak at 1.23 μm with 0.14 μW light output from the edge of device under 1.0 kA/cm^2 current excitation. The EL peak wavelength is longest ever reported even it has less Bi composition compared to previous reports.

Tu-P-29

Characterization of Valence Band Movement with Smoothly Varying Dilute Bi Content in GaAs using X-ray Photoelectron Spectroscopy

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The giant reduction in the bandgap energy of $GaAs_{1-x}Bi_x$ with the introduction of dilute Bi concentrations has gained much attention. This study employs a novel MBE-based synthesis technique employing a stationary substrate and pulsed fluxes to realize droplet-free $GaAs_{1-x}Bi_x$ surfaces with smoothly-varying Bi incorporation across the sample to study GaAsBi band structure. Bi incorporation was quantified using X-ray diffraction. X-ray photoelectron spectroscopy data were interpreted to quantify the movement of the valence band with increasing Bi incorporation. Furthermore, the impact of alloying and strain on valence band shifts were deconvolved.

Tu-P-30

Molecular Beam Epitaxy of GaAs/GaAsBi Heterostructure Nanowires

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We grow GaAs/GaAsBi core-multi shell nanowires by molecular beam epitaxy. The wire diameters were precisely controlled by adjusting the growth procedure.The surface was smooth for the GaAs/GaAsBi core-shell nanowires at small Bi concentration. On the contrally, the introduction of Bi, assumed to be larger than 2% Bi, induces specific surface roughening.Thatroughening wasobserved after the growth of GaAsBi with sharp and short period perturbations at the upper side of the nanowire. By the growth of the GaAs outer shell, the morphology gets loosened. Further, disordered structure was observed at the bottom side of the nanowire. These results suggest strong structural modifications of the nanowire during the GaAs growth by the introduction of Bi.

Tu-P-31

Characteristics of GaInNAs-based intermediate band solar cells

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Intermediate band solar cells have the potential to overcome the efficiency limit of single-bandgap solar cells. Dilute nitride III-V alloys, with splitting of the conduction band due to band anti-crossing, can be used as the intermediate band material for solar cell applications. In this work, we report the comparison of performances of Ga(In)NAs-based IBSCs with different indium and nitrogen content grown on GaAs(100) substrate. The $Ga_{0.97}In_{0.03}N_{0.01}As_{0.99}$ based solar cell structure shows room temperature photoluminescence emission at 1.18 eV.

Dilute Nitrides and Bismides

Tu-P-32

InGaAsBi materials grown by gas source molecular beam epitaxy

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In this work, the InGaAsBi epilayers were optimized and grown successfully by V90 gas source molecular beam epitaxy (GSMBE). Elemental indium and gallium, hydrides (AsH_3 and PH_3), Si and CBr_4(C) were used as group-III, group-V, n-type and p-type doping sources, respectively. The lattice mismatch of the InGaAs and InGaAsBi epilayers to InP substrate were measured by high-resolution X-ray diffraction (XRD). The Bi concentration was determined by Rutherford Backscattering Spectroscopy (RBS). The electron concentration and room-temperature mobility of the n-type and p-type epilayers were measured by Hall measurements.

Oxide and Hybrid Epitaxial Systems

Tu-P-33

GaAs Metal-Oxide-Semiconductor Push with Molecular Beam Epitaxy Y_2O_3 – in comparison with atomic layer deposited Al_2O_3

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In-situ molecular beam epitaxy (MBE) Y_2O_3 films 1-2 nm thick were found to be single crystalline epitaxially grown on GaAs(001)-4×6 reconstructed substrates. The Y_2O_3 films are of cubic phase with (110) as the normal, having the film/substrate orientation relationship of Y_2O_3(110)[001][**1**10]//GaAs(001)[110][1**1**0]. Despite of a large lattice mismatch, the hetero-structures exhibit outstanding 900°C thermal stability, excellent capacitance-voltage (CV) characteristics, and low leakage current densities of < 10^{-8} A/cm^2 at ±4 MV/cm. The frequency dispersion of the measured CVs of the Y_2O_3/GaAs(001) is ~4.6 % for p-GaAs and ~12.4 % for n-GaAs, lowest ever achieved in the oxides on GaAs(001). Moreover, low interfacial trap densities (D_{it}'s) of (3-5)×10^{11} eV^{-1}cm^{-2} with no discernible peaks at the mid-gap were measured using the conductance method (GV). In contrast, the atomic layer deposition (ALD)-Al_2O_3/GaAs shows large CV frequency dispersion especially for n-GaAs, large D_{it} with large peak at the mid-gap, and low thermal stability.

Oxide and Hybrid Epitaxial Systems

Tu-P-34

Comparison of Molecular Beam Epitaxy and Atomic Layer Deposited high-k oxide/ III-V interface - Y_2O_3/GaSb(001)

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The intensive study of interfacial properties of MBE- and ALD- high-k oxides on III-V is conducted in the past decades. In our study, both MBE- and ALD-Y_2O_3 on GaSb show decent capacitance-voltage characteristics. Nevertheless, MBE-grown Y_2O_3 outperform ALD-oxide in interfacial trap densities. In-situ X-ray photoelectron spectroscopy was applied to analyze the interfacial bonding, showing that MBE-grown oxide had more GaO_x at the interface than those ALD-grown samples, which may be the key to passivate III-V compound semiconductors.

Tu-P-35

Epitaxial Growth of Rocksalt $Zn_{1-x}Mg_xO$ on MgO (100) Substrate

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$Zn_{1-x}Mg_xO$ epilayers with x = 0.2 - 0.8 have been grown on MgO (100) substrate by molecular beam epitaxy at two substrate temperatures, 400°C and 600°C, respectively. X-ray reciprocal space map measurement revealed that the epilayers were grown in a polymorphic mode with no strain relaxation at low Zn contents. Moreover, the epilayers exhibit a smooth surface and low full width at half maximum values (180 - 1260 acrsec) of the $(200)_{ZnO}$ rocking curve.

Oxide and Hybrid Epitaxial Systems

Tu-P-36

Characterization of Ga_2O_3 Films on C-plane Sapphire Substrates Grown by Plasma-Assisted Molecular Beam Epitaxy

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The Ga_2O_3 thin films in similar thickness were grown on c-plane sapphire substrates at various growth temperatures from 550 to 800°C. The influences of growth temperature on growth rate, surface morphology, crystal structure and crystal quality were investigated in detail. The growth rate reduces with the increasing of the growth temperature. The surface morphology and RMS roughness values of films depend strongly on the growth temperature. The (-201) oriented β-Ga_2O_3 thin films grown on c-plane sapphire substrate has six-fold symmetry and β-Ga_2O_3<010> directions were parallel to Al_2O_3<1-100>directions. The crystal quality of thin films improved with increasing of growth temperature.

Dilute Nitrides and Bismides

Tu-P-37

GaAsPN Absorbers Grown on GaP for Multijunction Solar Cells: Optical Absorption and Thermal Conductivity Properties

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Optical absorption and thermal conductivity of GaAsPN absorbers grown on GaP are investigated by optical absorption spectroscopy and photo-thermal deflection spectroscopy (PDS). First, the strong dependence of optical absorption on As content is shown: with a maximum absorption coefficient of 38,000 cm^{-1} below the GaP bandgap. Optical absorption and thermal conductivity of the samples are then evaluated for various growth and annealing conditions using PDS. The significantly positive impact of annealing on both properties is demonstrated. Thermal conductivity reached 4W/mK for the best sample. These results are promising for the development of absorbers in multijunction solar cells.

MBE grown Devices

Tu-P-38

GaAsPN Single and Tandem Solar Cells on Silicon

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The development of a III-V on silicon tandem cell is reported. GaAsPN material is considered for top cell absorber because of its quasi-lattice matching with silicon and its pseudo-direct bandgap at 1.7 eV. First, GaAsPN single cells are grown on both GaP and Si substrates, and their electrical performances are compared. It is found that the performances of the cell are limited by the low carrier mobility induced by the use of dilute nitrides. Then the first-stage development of a tandem photovoltaic solar cell is reported, including a tunnel junction (TJ) made of Si.

Tu-P-39

Visible AlGaInP light-emitting devices grown on high-index substrates

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We present a comparative study of light emitting diodes covering green to red spectral region, grown on (100) and high-index (311)A and (211)A substrates in same MBE growth run. GaP based electron barrier was used to prevent escape of nonequilibrium electrons into cladding layer. Devices grown on high-index substrates produced higher output power and shorter emission wavelength. Green electroluminescence near 550 nm was achieved on (211)A substrate at room temperature. Lasers performance for structures on high-index substrate is also presented.

MBE grown Devices

Tu-P-40

Surface plasmon resonance sensing of highly doped InAsSb/GaSb nanoribbons.

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Highly Si-doped InAsSb/GaSb are demonstrated as an alternative for plasmonic applications in the mid-infrared overwhelming the limitations shown by gold resonators. We report a fine-tuning procedure, based on tailoring ribbon width and doping level, to adjust the LSPR properties and to obtain low-loss plasmonic materials. Both, decreasing ribbon width or increasing doping level, result in a blueshift of the resonance peak. We further show surface plasmon resonance (SPR) sensing to different bulk absorbing polymers and we evaluate the effect of the absorbing layer thickness on the sensing properties. These results make InAsSb/GaSb promising candidates for the development of biosensing devices.

III-V compounds

Tu-P-41

Electron transport properties of InSb/GaInSb composite channel high electron mobility transistor structures

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We investigate the electron transport properties of high electron mobility transistor (HEMT) structure with the novel InSb/$Ga_{0.35}In_{0.65}Sb$ composite channel, which is grown on a (100) GaAs substrate by molecular beam epitaxy. After optimizing the amount of Te δ-doping into the $Al_{0.4}In_{0.6}Sb$ barrier layer and the growth temperature, we achieve the high electron mobility of 11,200 cm^2/Vs and the large sheet electron density of 2.1× 10^{12} cm^{-2}, respectively. These results indicate that the InSb/$Ga_{0.35}In_{0.65}Sb$ composite channel HEMT structure is suitable for the ultra-high-speed and low-power-consumption devices.

MBE grown Devices

Tu-P-42

InSb-based HEMTwith Over 300 GHz-f_T using $Al_{0.25}In_{0.75}Sb/Al_{0.15}In_{0.85}Sb$ stepped buffer layer for strain reduction

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We fabricated InSb high electron mobility transistors (HEMTs) using the $Al_{0.25}In_{0.75}Sb/Al_{0.15}In_{0.85}Sb$ stepped buffer layer grown on a (100) GaAs structure by molecular beam epitaxy (MBE) and measured their DC and RF performances at room temperature. The epitaxial structure had an electron mobility (μ) of 17,700 cm^2/Vs with a sheet carrier concentration (Ns) of 1.1×10^{12} cm^{-2}.As the result, we obtained a maximum transconductance (g_{m_max}) of 0.88 S/mm and a cutoff frequency (f_T) of 302 GHz for the 50-nm-gate HEMT when biased at a drain-source voltage (V_{ds}) of 0.5 V.

Tu-P-43

Metamorphic InAs quantum well lasers on InP substrates with different well shapes and waveguides

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The effects of well shapes and waveguides on InP-based InAs quantum well lasers around 2.5 μm have been investigated. The laser structures were grown on metamorphic $In_{0.65}Al_{0.35}As$ buffers. A novel trapezoidal quantum well composed of InAs/$In_{0.53}Ga_{0.47}As$ grading layer and InAs layer was used to relieve the strain and improve the quality of quantum well. $In_{0.65}Al_{0.2}Ga_{0.15}As$ waveguide was applied instead of $In_{0.65}Ga_{0.35}As$ to enhance the carrier injection into the active region. The lasing properties, threshold current and output power were investigated at different temperatures. Results show that InAlGaAs waveguide and trapezoidal quantum well were able to improve the laser performances.

MBE grown Devices

Tu-P-44

A Comparative Study on HfO2/Al2O3/GaSb Capacitors Prepared by *In-situ* Process and Hydrogen Plasma Treatment Process

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HfO_2/Al_2O_3/p-GaSb metal-oxide-semiconductor capacitors (MOSCAPs) with low density of interface traps (D_{it}) near the valence band have been prepared by an *in-situ* process and a hydrogen plasma treatment process for the air-exposed GaSb surface. While both methods produce MOSCAPs with similar electrical characteristics, x-ray photoemission spectroscopy studies on the oxide-semiconductor interfaces indicate that the in-situ process provides an oxide-free interface, but a thin layer of Ga_2O_3 appears at the oxide-semiconductor interface for the hydrogen plasma treated devices. Both processes can produce MOSCAPs with low D_{it}, making high-performance Sb-based MOS-devices feasible for future applications in low-power logic integrated circuits.

MBE grown Devices

Tu-P-45

Ultra-Violet Light Emitting Diodes based on III-Nitride Quantum Dots

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Light emitting diodes (LEDs) based on $Al_xGa_{1-x}N$ materials are intensively investigated for the fabrication of ultra-violet (UV) sources. GaN quantum dots (QDs) are attractive for their use as the active region of such LEDs. Taking advantage of the epitaxial strain, QD-based heterostructures have been grown on both (0001) and (11-22) surface orientations. Different QD designs have been fabricated and the resulting LED structures investigated by electro-optical and structural measurements. We show that most of the UV-A region can be covered, with (0001) LEDs emitting at longer wavelengths (> 350 nm) and (11-22) LEDs at shorter ones (< 350 nm).

MBE grown Devices

Tu-P-46

Internal Field Engineering in InGaN Quantum Wells Grown by PAMBE

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Impact of build in electric fields on the internal efficiency of InGaN/InGaN quantum wells (QWs) grown on bulk gallium substrates has been studied. Structures were grown using high nitrogen flux in plasma-assisted molecular beam epitaxy (PAMBE) reactor. Possibility of obtaining close to single monolayer of different composition during QWs growth was exploited leading to 2 to 3 times higher emission intensity.

Tu-P-47

Investigating InGaAs quantum well based microcavity system for polariton condensation

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Studying Bose Einstein condensation (BEC) in semiconductor micro cavities is very exciting and challenging, as very specific samples are needed. To study this phenomenon III-V materials have been studied extensively. Micro cavities comprised of thick layer of active material placed between two stacks of Distributed Bragg reflectors (DBRs) of corresponding wavelength are typically grown using molecular beam epitaxy (MBE). Here, I will present results of our studies carried out on InGaAs quantum well (QW) based micro cavity system with GaAs/AlGaAs DBRs. QWs stacks are studied with and without DBRs to map a thorough understanding.

MBE grown Devices

Tu-P-48

Spectrally Uniform Quantum Dot Single Photon EmitterArrayIntegrable with Multifunctional Dielectric Metamaterials: Towards Quantum Information Processing

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We report on a new paradigm for realizing on-chip integrated nanophotonic systemscomprisingregular arrays of mesa-top quantum dot (MTQD) spectrally uniform single photon sources (SPS) (realized via substrate-encoded size-reducing epitaxy (SESRE)) and dielectric multifunctional metamaterials for simultaneous enhancement of optical excitation and lossless on-chip propagation of the MTQD emission utilizing collective magnetic multipole modes. A uniform $g^{(2)}(0)$ value of 0.24±0.07 is demonstrated at 77.4K for the MTQD array over ~1000μm^2 area with a spectral uniformity of ~8.3nm. Integrated systems comprising MTQD SPS array and dielectric metamaterials will serve as a unit for hierarchical architectures towards on-chip quantum information processing.

Tu-P-49

Superradiant single-photon emission from a quantum dot

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We report the observation of single-photon superradiance from an exciton in a semiconductor quantum dot. This has been achieved by exploiting large GaAs quantum dots formed by intentional thickness fluctuations in a quantum well. The confinement is strong enough for it to mimic a two-level atom, yet sufficiently weak to ensure superradiance. The electrostatic interaction between the electron and the hole comprising the exciton gives rise to an aharmonic spectrum, which we exploit to prepare the superradiant quantum state deterministically with a laser pulse. We observe a five-fold enhancement of the oscillator strength compared to conventional quantum dots.

Tu-P-50

III-V's Quantum Dots for Intermediate Band Solar Cells

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In this work we study a quantum dot sol... ure as an alternative to the most studied InAs/GaAs system, to extend ... band solar cell design flexibility. The structure consists of high energy A... with embedded InAs quantum dots via a multistep growth approach. ... characterization confirms the effectiveness of this approach in containin... ation. Charge carrier thermal transfer and inter-level filling processes w... ar cell device are influenced by the applied growth approach, as a det... modulated optical spectroscopy investigation shows.

Withdrawn

Tu-P-51

Fabrication, characterization and simulation of MBE-grown GaAs-based tunneldiodes with type I and type II heterojunctions for multi-junction solar cells

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In this work, GaAs based tunnel junctions were grown by Molecular Beam Epitaxy (MBE) to study the interband tunneling mechanisms in such devices. Based on tunnel junctions experimental characteristics with various n-doping levels, we develop a simple numerical model able to quantify the magnitude of the tunneling current density, which shows that direct interband tunneling is the predominant tunneling mechanism in GaAs tunnel junction instead of trap-assisted-tunneling. Such results will lead us to develop a type II tunnel heterojunction based on n+ GaInAs(N) and p+ GaAsSb(N), which is of main interest for multi-junctions solar cells applications based on dilute nitride materials.

MBE grown Devices

Tu-P-52

Growth and characterization of cubic GaN/GaAs solar cell

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III-Nitrides integration with GaAs and its application in tandem solar cells is important because the predicted advantages to improve photovoltaics performance. In this work we studied a hetero-junction solar cell based con cubic-phase GaN/GaAs. We present the design, growth and characterization of n-GaN/i-GaAs/p+GaAs solar cell.

Tu-P-53

Investigation of long-wave type-II InAs/GaAsSb superlattice photodiodes grown on InAs substrates by molecular beam epitaxy

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Long-wave infrared InAs/GaAsSb superlattices grown on InAs substrates will be reported. The lattice mismatch between the superlattices and the InAs substrates was 1.0×10^{-5} and the root-mean-square roughness was 0.19 nm over a measured area of 2 μm×2 μm. The InAs-based superlattice devices had a 50% cutoff wavelength of 12.3 μm. The current responsivity of InAs-based devices reached to 2.4 A/W when the absorption region was p-doped to be 5.0×10^{15} cm^{-3}.

Tu-P-54

X-ray Response of GaSb Grown by Molecular Beam Expitaxy

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GaSb offers high stopping power and a low pair creation energy for x- and γ-rays, suggesting a wide range of applicable photon energies with enhanced spectroscopic resolutions for a given absorber thickness. In this work, we demonstrated the x-ray response of GaSb, and studied the energy spectrum from a 241Am radioactive source using GaSb photodiodes. The primary photopeaks were clearly identified and showed a good detection linearity. The measured energy resolution of 1.46 keV at 13.9 keV is found to be strongly limited by the electronic noise present in the measurement system.

Tu-P-55

Study of surface passivation on InAs/GaSb superlatice photodetectors with side-wall gate controlled structure

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In this paper, we studied different passivation techniques and the dielectric film-semiconductor interface properties for InAs/GaSb superlattice photodetectors. We found that with Si_3N_4 passivation, the R_0A of the superlattice detector decreased from $2.8\times10^5\Omega cm^2$ to $12\Omega cm^2$ at 80K after a process of rapid thermal annealing (RTA) at 250°C for 60s. Excessive surface charge of 6.15×10^{12}cm^{-2} was measured from a gate-controlled structure. Meanwhile, the SiO_2 passivated devices can sustain its electrical performance after the RTA process.

MBE grown Devices

Tu-P-56

Analysis of temperature gradient QCL active region as a function of number of cascades

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We describe the realization of a series of QCLs emitting at 4.6 µm using gas-source molecular beam epitaxy. The number of cascades in the active region was chosen to cover the range between 5 and 40. By reducing the number of cascades for a fixed active region design we obtain larger threshold current densities but lower threshold power density. A method is presented to determine temperature gradient in active region at threshold. Reducing the number of cascades leads to decrease total threshold temperature, indicating the possibility of achieving the continuous mode with fewer number of cascades.

Tu-P-57

Thermal Annealing Of Lattice-Matched InGaAs/InAlAs Quantum Cascade Laser

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We describe the evolution of optical power, threshold current, and emission wavelength of a lattice-matched InGaAs/InAlAs quantum-cascade laser (QCL) emitting at 13 µm grown by gas-source MBE and annealed at 600°C; 650°C, and 700°C. No change in threshold current and emission wavelength was observed. We observed a marked increase in slope efficiency and maximum emission power for the 600°C anneal, but degradations for higher annealing temperatures. This result stands in contrast with the observation that strain-compensated structures cannot withstand annealing temperatures of 600°C.Useful information for post-growth processing steps and the role of interface roughness in QCL performance are obtained.

Tu-P-58

Barrier structures of InAs/GaSb type-II superlattices LWIR photodetectors

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We grew and compared two InAs/GaSb superlattices longwavelength infrared photodetectors with different barrier structures, one with InAs/AlSb and the other with InAs/GaSb as hole barriers, respectively. Our results show that similar performances can be achieved from SL detectors with the different hole barriers although InAs/AlSb superlattices can provide a larger valence band offset or barrier. Detailed comparison of their characteristics, such as dark currents, responsivity, etc., and their in-depth analysis will be presented at the conference.

Tu-P-59

Two-Color Surface Emitting Lasers by a GaAs-Based Coupled Multilayer Cavity Structure for Novel Coherent Terahertz Light Sources

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Two-color surface emitting lasers were fabricated using a GaAs-based coupled multilayer cavity structure grown by molecular beam epitaxy. InGaAs/GaAs multiple quantum wells were introduced only in the topside cavity for two-mode emission in the near-infrared region. Two-color lasing of the device was successfully demonstrated under pulsed current operations at room temperature. We also observed good temporal coherence of the two-color laser light using a Michelson interferometer. A novel type of coherent terahertz light source is expected when the other side cavity can be responsible for difference-frequency generation of two modes by the second-order nonlinearity.

MBE grown Devices

Tu-P-60

Ordered array of Self-Catalyzed GaP Nanowires on Patterned Si Substrates For Photovoltaic Applications

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We grow self-catalyzed GaP nanowires on Si(111) substrates, using a nano-patterned SiO_2 mask to obtain an ordered array. We compare our results obtained with different growth and processing conditions, and discuss how this can be the first building block for the realization of nanowire-based photovoltaic devices.

Tu-P-61

Time Resolved Photoluminescence of Chalcopyrite Materials $CuGaSe_2$/$CuInSe_2$ Single Quantum Well

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$CuGaSe_2$ and $CuInSe_2$ single quantum well layers are grown on GaAs (001) by employing the deposition sequence of migration enhanced epitaxy (MEE) using a molecular beam epitaxy system. The carrier lifetime of the quantum well is measured via time-resolved photoluminescence (TRPL). By using the single exponential fitting, the PL decay time is 21.5 ps. Carrier lifetime increases with increasing of the measurement temperature. The carrier lifetime of CGS/CIS SQW is smaller comparison to GaAs. The shorter carrier lifetime may indicate the contribution of non-radiative recombination.

Tu-P-62

Improved photoluminescence from InAs/(Al)GaAs quantum dots for intermediate band solar cells

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Self-assembled InAs quantum dots with improved photoluminescence has been grown by molecular beam epitaxy. The influences of the InAs growth rate, In:As flux ratio and the substrate temperature on the self-assembled InAs quantum dots were investigated via photoluminescence. The InAs quantum dot samples grown at 480°C with 0.3 ML/s growth rate show improved photoluminescence, compared to other growth rates and lower growth temperature. The performances of InAs/(Al)GaAs quantum dot solar cells will be presented.

Tu-P-63

Surface-enhanced absorption on InGaAs/InAlAs avalanche photodiode structures operating at 1.55 µm by gallium nanoparticles evaporation

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The aim of this work is to investigate the electrical and optical characteristics of modified InGaAs/InAlAs-based avalanche photodiodes (APDs), where Ga NPs, with an average diameter of 23± 10 nm, have been deposited on their unpassivated surfaces. The NPs presence leads to a 10-25% improvement of the device photo-response above the punch-through voltage under illumination at 1.55 µm. The improvement is attributed to a larger light absorption in the device structure resulting from the better electromagnetic coupling of incident radiation at the device surface. To minimize the dark current, a thin PMMA layer is inserted between the NPs and the mesa structure of the device.

Tu-P-64

Improvement in surface morphology of GaSb buffer layer by 2-step high and low temperature growth

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In this report, we investigated the effect of GaSb growth temperature in the case of GaSb-MBE growth with Sb_4 to obtain a smooth surface. By changing the growth sequences with the usage of Sb_4, we found that 2-step growth at high temperature (HT) followed by that at low temperature (LT), where both growths proceed in a step-flow mode, provides a smoother surface than GaSb growth only at HT.

Tu-P-65

Anomalous Incorporation of B into $B_xGa_{1-x}As$ Layers

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$B_xGa_{1-x}As$ layers can be used for strain balancing in combination with compressively strained materials. In contrast to the common group III metals, the incorporation behavior of B is shown to be more complex. The apparent BAs growth rate in $B_xGa_{1-x}As$/GaAs superlattices is shown to depend on the GaAs growth rate, where a higher Ga/B ratio leads to an increased B incorporation. Compositional analysis by high-resolution X-ray diffraction is complemented with atomic force microscopy, which reveals pronounced roughness for low GaAs growth rates and smooth surfaces for high Ga/B ratios.

Tu-P-66

Compositional analysis of InSb sub-monolayer quantum dots within (Al)GaSb-based barriers grown on GaAs

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InSb quantum dots (QDs) with applications in mid-infrared photonic devices have been grown on GaAs substrates surrounded by two types of barrier matrix: GaSb and AlGaSb. These structures have been analyzed by diffraction contrast transmission electron microscopy (TEM), showing good structural quality. High Angle Annular Dark Field (HAADF) images with atomic column resolution have been taken to investigate the In distribution in detail. Simulations of the HAADF images are helpful to analyze the small In-content in sub-monolayer quantum dots and to have a better understanding of the overall composition distribution in these heterostructures.

Tu-P-67

Atomistic Evolution of (n×3)-reconstructed Areas of InAs-GaAs(001) Surface during MBE Growth

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We investigate the spatial evolution of (n×3) surface reconstructed areas during the MBE growth of InAs-GaAs(001) in order to understand the mechanism of consequent QD nucleation. Statistical analysis of the continuous length of As dimer rows, relating to the number n, reveals that the fraction of (8×3) reconstructed areas become dominant rapidly in the latter stage of the growth. This result is consistent with a preceding ab initio-based calculation of chemical potentials. It is suggested that the (n×3) areas hence grow to form patch-like domains as QD nucleation sites.

Tu-P-68

Effect of Gallium Composition in AlGaAsSb alloys for Avalanche Photodiodes

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Novel AlAsSb materials for avalanche photodiodes are expected to substantially reduce excess noise factors to allow detection of low energy signals. It has been shown that when Gallium is introduced in the avalanche layer, the surface leakage current is significantly reduced. We demonstrate the measurements and analysis of two AlGaAsSb samples grown on InP substrates with different Gallium concentrations in the AlAsSb layer using photoreflectance and photoluminescence characterization techniques.

Tu-P-69

Improving Wet Etching of InGaAs/AlGaAsSb Avalanche Photodiodes

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Avalanche photodiodes are already established components in high-speed optical receivers for optical communication systems. They are also found in signal detection of very low number of photons, e.g. optical single photon counting or X-ray photon detection. We are developing InGaAs/AlGaAs Separate-Absorption-Multiplication avalanche photodiodes for X-ray photon detection. To achieve mesa test devices sufficiently robust for characterization, we evaluate two wet chemical etching recipes by comparing mesa profiles from Scanning Electron Microscope and dark current-voltage characteristics. Differences observed in mesa profile and uniformity of dark current-voltage characteristics underline the importance of obtaining devices with mesa profiles that are closer to ideal.

Tu-P-70

On the structural and optical properties of GaAsBi quantum wells and thin layers grown on GaAs by molecular beam epitaxy

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GaAsBi quantum wells and thin layers with various compositions up to 5.4% and 7.5% have been grown by molecular beam epitaxy. We present an overview of the results we have obtained on these dilute bismide alloys. They have been characterized by HR-X ray diffraction, secondary ion mass spectrometry, transmission microscopy, and time-resolved photoluminescence. We will discuss their growth conditions, structural properties (composition and its homogeneity, strain, defects) and their optical properties showing the presence of localized states which effet can be decreased by rapid thermal annealing.

Tu-P-71

Resonant linewidth narrowing of single quantum dot emission using weak, above-band light

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Single InAs-based quantum dots in distributive-Bragg reflector microcavities are bright sources of single indistinguishable photons. For resonant pumping, we couple pump light into a lateral waveguide mode of the microcavity and detect surface normal, separating the strong pump from the single-photon emission. With this geometry we investigate the change in single-photon brightness and linewidth when adding weak, above band light to the resonant excitation. This additional light is too weak to alter the single photon statistics but can increases the peak intensity by nearly an order of magnitude and decrease the spectral linewidth by a factor of two.

Tu-P-72

Determining The Capacitance of Diodes with High Leakage Currents

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Determining the capacitance of diodes exhibiting a high surface leakage current and hence a small shunt resistance can be challenging. Yet knowledge of a diode's capacitance is often crucial in understanding or predicting the diode's high-frequency performance, for example in high-speed lasers and photodiodes. Conventional fixed-frequency, two-element models (a capacitor with a series or parallel resistor) fail to produce reliable capacitance values when applied to such devices, because high surface leakage currents degrade Q-factor, affecting accuracy of the deduced capacitance values. Therefore a robust, three-element model is employed to extract the capacitance values of these diodes.

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AUTHORS

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Time	Sunday, Sept. 4	Monday, Sept. 5	Tuesday, Sept. 6	Wednesday, Sept. 7	Thursday, Sept. 8	Friday, Sept. 9
8h30		Opening 8h30 - 8h50	Dev Cordier / Oxi / Spin	2D Bell / Oxi / Nano	Fund Ito / Dil / Nano	
9h00		Plenary Arakawa - 8h50-9h40	Stemmer	Schlom	Kudrawiec	Wide Speck / Dev / III-V
9h30		Plenary Chambers - 9h40-10h30				Vizbaras
10h			Yoshimi		Gonzalez	Coffee break 10h10-10h40
10h30		Coffee break 10h30-11h	Coffee break 10h20-10h50	Coffee break 10h20-10h50	Coffee break 10h20-10h50	Wide / Late news / Nano
11h		Plenary Brüne - 11h00-11h50	Dev / III-V / Wide	2D Jia / Oxi / Dil	Fund / II-VI / Nano	
11h30						
12h		Photo 11h50-12h20				Student award and Closing session
12h30		Lunch 12h20 - 13h40	Lunch 12h20 - 13h40	Lunch 12h - 13h20	Lunch 12h20 - 13h40	
13h						10 min
13h30		Fund Bracker / Wide / Nano	IV Moutanabbir / III-V / II-VI		Dil Luna / Spin / Dev	invited (30 min)
14h		Mi	Bennet		Late news	contributed (20 min)
14h30						
15h		Koblmüller	Shen			
15h30		Break 15h30 - 16h	Break 15h30 - 16h	Excursions	Coffee break 15h30 - 16h	
16h	On-site registration	Refreshments and Poster session 16h-18h, sponsored by **Orsay Physics**	Refreshments and Poster session 16h-18h, sponsored by **ITN PROMIS**		Nano / Wide / Dev	
16h30						
17h						
17h30					Late news / Late news / Late news	
18h	Welcome reception, sponsored by **K Space Associates, Inc.**	Veeco user meeting	Riber user meeting		Conference dinner, sponsored by **RIBER**	