CENTRE FOR OPTOELECTRONICS

Department of Electrical and Computer Engineering
National University of Singapore

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Annual Report

Prepared by
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1. INTRODUCTION

The optoelectronics industry services sectors of economic activity ranging from consumer (DVD, displays), communication (telecom and datacom) and industrial (opto-isolators) applications. However, it is most closely associated with the optical communications industry which has been in the doldrums for several years now. A study on the Communications Technology Roadmap released in May 05 by the MIT Microphotonics Centre Industry Consortium, reports that it is not all gloom and doom, but "the industry stands at the threshold of a major expansion that will restructure its business processes and sustain its profitability for the next three decades." There will be greater convergence of electronics and photonics and a shift from components for information transmission to information processing and the coupling of communication-based optical devices with the input-output of electronic processors.

During the year, a patent, granted in October 03 on the fabrication of an optical waveguide switch using carrier injection to induce refractive index change, was licensed by INTRO to a subsidiary of Intellectual Ventures of the USA. Two patents were filed. One was on the method of patterning nanostructures on the substrate surface to enable the release of stress in the initial nucleating layers during heteroepitaxy. It is found that using this method also leads to the reduction of dislocations density in the epitaxial layer by an order of magnitude. This discovery resulted from a PhD research work. Another was on the use of dielectric grating in Distributed Feedback (DFB) semiconductor lasers. This patent provides a technique for enhancing coupling of the traveling waves which would result in a smaller device and resulting in a lower capacitance and thus is capable of working at higher frequencies. This piece of work was conducted in collaboration with the Institute of Materials Research and Engineering (IMRE).

One of the major continuing research efforts at the Centre has been the growth of GaN/InGaN on sapphire, free-standing GaN substrates and silicon for the fabrication of blue/green LEDs and lasers. The Centre has now the capability of producing LEDs emitting at 380 nm (UV), 400 nm (violet), 470 nm (blue) and 520 nm (green). The recent success is an LED giving a broad emission ranging from 400nm to 650 nm to give white light. A patent has been filed and the technique uses the growth of InGaN quantum dots. Following the earlier success of producing lasers emitting at 647 nm (AlInGaP), the first in the world to use more environmentally friendly precursors tertiarybutylphosphine (TBP), we are happy to report the fabrication of lasers emitting at 808 nm (for YAG pumping), 980 nm (for Er-doped fibre pumping) and 1.55 μm (for telecom lasers).

Collaboration with the Chemistry Department has resulted in a technique for the growth of ZnO single crystalline nanorods (2 μm in length and 80 nm in diameter) on GaN substrates. It makes use of an inexpensive process know as hydrothermal synthesis and the rods are vertically aligned. Strong band edge emission is obtained and laser pumping shows a narrowing of the emission spectrum signifying amplified stimulated emission. With the installation of a nitrogen RF-plasma cell into the MBE system, a new area of study in the dilute Nitrides, GaAsN and InGaAsN, has begun. These materials are important for emission at the 1.3 μm wavelength range for application in vertical cavity surface emitting laser (VCSEL). Collaboration with IMRE on these materials and on light emitting polymer is in progress.

P-type doping of GaN by beryllium (Be) implantation has been done. To prevent the loss of stoichiometry of the GaN surface due to nitrogen loss after prolonged annealing at high temperature, an AlN capping layer was used during annealing. We have achieved thermally stable ohmic and Schottky contact on n-doped GaN and AlGaN and minimum specific contact resistance is of the order of 5×10^{-8} ohm-cm^2. The Schottky contact remained stable after heat treatment at 300°C for 100 hours. Achieving low specific contact resistance and stable ohmic contact on p-doped GaN remains a challenge and it is one of areas currently under investigation. The work on ICP etching is preliminary and Centre has achieved a better understanding of the etching mechanisms.

Our students have won the Elsevier Student Travel Award for presenting a paper in the Electronic Materials Conference in Italy (Oct 04) and for the Best Poster Award in Symposium J at the ICMAT Conference 05 held in Singapore.(July 05).

The total project funding for the last six years is around **$10.1 M**. Currently, the Center's main activities are generated by **4** principal investigators with collaborations from **2** other staff members of the Department of Electrical and Computer Engineering, **5** staff members from the IMRE and **a** member from industry. The Centre provides postgraduate training where currently **36** students are working towards their M.Eng. or Ph.D. Since the inception of the Centre in 1989, **22** PhDs and **54** M.Eng. students have graduated. The facility has also been used by undergraduates for their final year project work, which numbers **20** in the past year. It is also been used for two undergraduate courses, one in the 3rd year and another in the 4th year for their laboratory experiments.

2. PERSONNEL

Staff Members Associated with the Centre for Optoelectronics

Professor SJ Chua, PhD., Wales (Director)
Associate Professor EF Chor, PhD., Southampton
Associate Professor LS Tan, PhD., Hawaii
Assistant Professor Xiang Ning, D.Tech., Finland

Postgraduate Students:

Currently there are 36 postgraduate students pursuing higher degrees at the Centre. They are listed below:

1. Agam Prakash Vajpeyi, M.Tech. (IIT KGP), India
2. Chang Chee Kiong James, B. Eng., Nanyang Technological University, Singapore
3. Cheah Chin Wei, B. Eng. (Hons., 1st Class), National University of Singapore
4. Chen Jingli, B. Sc., Jilin University, PRC
5. Chen Ao, B.Eng, University of Science & Technology of Beijing, PR China
6. Chua Cher Sian, B. Eng., (Hons), National University of Singapore
7. Fu Yijing, B. Eng., HuaZhong University of Science & Technology
8. Haryono Hartono, B.Eng., Nanyang Technological University, Singapore
9. Huang Leihua, B.Sc(Mat.Sci) Fudan University, PR China.
10. Jiang Jian, B. Sc., M. Sc., Fudan University, PRC
11. Keyan Zang, B. Sc., M. Sc., Tianjin University, PRC
12. Li Lip Khoon, B. Eng., (Hons), National University of Singapore
13. Li Xiaomin, B.S., Peking University
14. Liu Chong, B. Eng , National University of Singapore
15. Liang Ti, M.Sc., Beijing University.
16. Lim Chee Ho, B. Eng (Hons., 1st Class), National University of Singapore
17. Lim Chee Tiong, B. Eng (Hons., 1st Class), National University of Singapore
18. Lim Woon Chi, Janis, B. Eng , National University of Singapore
19. Ng Keh Ting, Doris, B. Eng , National University of Singapore
20. Poon Chyiu Hyia Debora, B. Eng , National University of Singapore
21. Qian Xinbo, M. Sc., Inst- of Semiconductor Physics, Chinese Academy of Science
22. Quang Lehong, B.Eng., Ho Chi Minh University of Technology, Vietnam
23. Soh Chew Beng, B. Eng., (Hons), National University of Singapore
24. Srinivasa Murthy Ravikiran, B. Eng., National University of Singapore
25. Tan Chung Foong, B.Eng, NUS, Singapore
26. Tan Wei Boon, B. Eng., National University of Singapore
27. Yu Hongyu, M.Sc Applied Science, University of Toronto
28. Zhang Chengwei, B. Eng., M.Eng., Xian Jiaotong University, PRC
29. Vernon Goh Tat Boon, B. Eng (Hons., 1st Class), National University of Singapore
30. Wang Haiting, , B. S., M.S., Xian Jiaotong University, PRC
31. Wang Xiaofeng, B. Eng., Northwestern Polytechnics University
32. Wang Yadong, B. S., M.S., Xian Jiaotong University, PRC
33. Yu Hongyu, M.Sc Applied Science, University of Toronto

The following students are pursuing their MSc and undertaking projects in the Centre for Optoelectronics.
Anu Austin, B. Sc., Anna University, Madras, India
Tey Aik Ping, B. Sc. (Electrical Eng., Cum Laude), Arizona State University, USA
Wang Jianwei, B. Sc., Beijing University, PRC

Graduating and Graduated Students

Mr. Zhang Ji submitted his Ph.D. thesis in May 2004 on the topic “Growth and characterization of GaInN”. He is now working as a Process Engineer at Veeco Asia, Shanghai, PRC.

Ms. Qian Xinbo submitted her Ph.D. thesis in July 2004 on the topic “Readout electronics for microbolometer infrared focal plane array” She is now working as a Research Fellow at Neural Network Laboratory, Electrical and Computer Engineering Department, NUS, Singapore.

Mr. Hou Yong Tian was awarded his PhD Degree in June 2004 on the topic, “Quantum modelling and characterization of deep submicron MOSFETs”.

Ms. Lim Hui Fern, Michele submitted her M.Eng thesis in July 2004 on the topic “Analysis of extended defects in InGaAIP grown by metal-organic chemical vapour deposition using tertiary-butyl phosphine.” She is now pursuing her PhD degree at University of New York, U.S.A.

Mr. Lee Chee Leong was awarded his M.Eng. Degree in July 2004 on the topic “Investigations on ohmic contact to p-doped gallium nitride”.

3. EARCH PROGRAMMES AND ACHIEVEMENTS

1. **Study on Nitride Materials and Their Opto-electronic Devices**
   Xiang Ning, Liu Hongfei, Lin Fen and Vivek Dixit

   This project deals with two nitride material systems, GaN and diluted nitride Ga(In)AsN, for short wavelength and long wavelength applications, respectively.

   GaN based blue lasers allow data storage with much higher density than traditional red lasers due to the much smaller beam spot of short wavelength blue light. On the other hand, high speed recording also need high speed light source. In this project, we are going to develop the GaN-based semiconductor saturable absorbers which will be used in mode-locking GaN semiconductor lasers for producing ultrafast short wavelength optical pulses. Another material system in this project is the III-V nitride (so called diluted nitride). Diluted nitride extends the wavelength to another direction, the long wavelength. This material has the applications for fiber optic communication wavelengths, 1.3 and 1.55 μm.

2. **Influence of substitutional carbon incorporation on implanted-indium-related defects and transient enhanced diffusion**
   C.F. Tan, and E.F. Chor

   It has been demonstrated that, by incorporating a thin ~20 nm $Si_{1-y}C_y$ (with *y* as low as 0.1%) layer at the deep indium implant end-of-range (EOR) region, the EOR defects and enhanced diffusion behavior associated with indium implant can be eliminated. The $Si_{1-y}C_y$ layer was grown epitaxially followed by a silicon epitaxy cap of 60 nm. Indium implantations were performed at $1x10^{14}$ cm^{-2} at 115 keV followed by spike annealing at 1050 °C. The experimentally observed EOR defect and enhanced diffusion elimination are explained based on the undersaturation of implantation-induced silicon interstitials with the presence of substitutional carbon at the $Si_{1-y}C_y$ layer.

3. **Enhanced Surface Passivation Properties of HfO_2 over SiO_2 or Si_3N_4 for AlGaN/GaN High Electron Mobility Transistors**
   C. Liu, and E.F. Chor

   It has been observed that HfO_2 exhibits better passivation properties than SiO_2 or Si_3N_4 on the performance of AlGaN/GaN high electron mobility transistors (HEMTs). Maximum drain current ($I_{D,max}$) and peak extrinsic transconductance ($g_{m,max}$) are better enhanced by HfO_2 passivation than SiO_2 or Si_3N_4, owing to a higher channel carrier concentration and mobility. The improvement in $I_{D,max}$ and $g_{m,max}$, with respect to unpassivated HEMTs, are 20% and 18%, respectively for HfO_2 passivated HEMTs. Although SiO_2 passivation leads to a higher gate leakage ($I_{g,leak}$), Si_3N_4 or HfO_2 passivation results in a lower $I_{g,leak}$. Similar observation is made for subthreshold current (I_{th}) measurements. HEMTs passivated with SiO_2 show a higher I_{th}, while those with Si_3N_4 or HfO_2 passivation exhibit a lower I_{th}.

4. **Leakage Suppression of Gated Diodes Fabricated under Low Temperature Annealing with Substitutional Carbon $Si_{1-y}C_y$**
   C.F. Tan, and E.F. Chor

   We have demonstrated the fabrication of n^+-*p* gated diodes using low temperature annealing of 700 ˚C for 30 s with a significantly reduced junction leakage current. This is achieved with the incorporation of an epitaxially grown $Si_{1-y}C_y$ (*y = 0.0007*) layer in the substrate located at the end-of-range (EOR) of arsenic implantations. The carbon devices show effectively suppressed EOR defects in the XTEM images and leakage characteristics similar to the controlled silicon device fabricated under high temperature annealing of 950 ˚C for 30 s. Arrhenius measurement of the leakage profiles has indicated identical leakage mechanism for both the pure silicon and carbon devices, thus signifying the substantial elimination of the secondary EOR defects resulted from the implantations despite the low temperature annealing of the latter. The advantage of such a scheme can be further exploited for near-zero of dopant diffusion beyond the sub-65 nm regime.

5. Effects of chemical and plasma surface treatments on O_2-annealed Ni/Au contact to p-type GaN
J.W.C. Lim, E.F. Chor and L.S. Tan

The effects of boiling Aqua Regia (AQ), N_2/Cl_2 plasma followed by AQ and O_2 plasma followed by AQ surface treatments prior to Ni/Au (20 nm/20 nm) metallization to p-GaN:Mg ($\sim3\times10^{17}$ cm^{-3}) have been investigated. N_2/Cl_2 plasma was employed in a bid to lower the Ga/N and O/Ga ratios of the GaN surface to improve the contact properties to p-GaN, while O_2 plasma was employed as an alternative to incorporate O into the Ni/Au system. Results show that a low Ga/N ratio does not necessarily correspond to a better contact. The positive effect of O_2 over N_2 anneal is observed only for the AQ-treated sample, although the mechanisms responsible for its positive effect: NiO formation and Ni/Au layer-reversal were observed for all O_2-annealed contacts. We conclude that the effect of O_2 anneal on the Ni/Au contact is dependant on the p-GaN surface prior to metallization.

6. AlGaN/GaN HEMT with Implanted Ohmic Contacts
H.T. Wang, L.S. Tan and E.F. Chor

Selective-area silicon implantation for source/drain was integrated into molecular beam epitaxy (MBE) grown AlGaN/GaN HEMTs. The successful activation (~15%) was achieved by rapid thermal annealing (RTA) at 1100°C in flowing N_2 ambient for 120 s with AlN encapsulant. Linear transmission line method (LTLM) measurements showed that the resistance of overlay Ti/Al/Ni/Au ohmic contacts was reduced to 0.44 Ω-mm by implantation doping. After the Schttoky Ni/Au gate formation, the typical DC characteristics displayed a higher current drive, smaller knee voltage and better gate control properties for HEMTs with implanted source and drain regions.

7. Surface Analysis of plasma treated p-GaN for contact formation
L.K. Li, L.S. Tan and E.F. Chor

The surface conditions of GaN treated by N_2, Cl_2 or N_2/Cl_2 plasmas followed by an aqua-regia wet etch were investigated via AES, AFM and PL. The AES results show an N-rich GaN surface on most of the samples after surface treatment. However, where a low N/Ga ratio has often been used as an indicator for N-vacancies (V_N) formation to quantify improved *n*-type GaN contact performance, there is no correlation of a higher N/Ga ratio to better *p*-type GaN contacts in this experiment. The PL spectra, on the other hand, show a trend of contact performance being tied to high band-edge (~3.42eV) intensities and low PL intensities at 3.27 eV, which has been identified as the donor-acceptor-pair (DAP) peak. It appears that plasma treatment induces enhanced compensation on the *p*-type GaN surface resulting in a deterioration of contact performance despite an N-rich GaN surface which is widely believed to give Ga-vacancies (V_{Ga}) that would lead to improvements in *p*-type GaN contact characteristics.

8. Two-dimensional Photonic Crystals Fabricated by Nano-imprint Lithography
S.J. Chua , A. Chen and B.Z. Wang

Photonic crystals are periodic dielectric structures that have so-called photonic bandgaps, which prohibit the propagation of photons having frequencies within the bandgap region. In recent years two-dimensional (2-D) photonic crystal slab structures attract a lot of interest, and a variety of applications have been demonstrated such as 2-D photonic crystal defect lasers, 2-D photonic crystal band edge lasers, 2-D photonic crystal waveguides and 2-D photonic crystal light-emitting diodes.

Despite the fact that novel high-performance optical devices have been implemented using 2-D photonic crystals, the commonly used fabrication method of electron-beam lithography (EBL) refrain them from real commercial applications. Therefore, alternative nanometer-size patterning techniques are under investigation, among which nanoimprint lithography (NIL) is promising in terms of its low-cost and high-throughput. Basically NIL involves a physical deformation of a thin layer of polymer deposited on a substrate by using a rigid mould, followed by a pattern transfer and the complete removal of the residual polymer in the recessed areas of the pattern.

The nickel mould with 2-D photonic crystal patterns covering the area up to $20mm^2$ is produced by electron-beam lithography (EBL) and electroplating. Periodic pillars as high as 200nm to 250nm are produced on the mould with the diameters ranging from 180nm to 400nm. The mould is employed for nanoimprinting on the poly-methyl-methacrylate (PMMA) layer spin-coated on the silicon substrate. Periodic air holes are formed in PMMA above its glass-transition temperature and the patterns on the mould are well transferred. This process can be utilized for commercial applications of photonic crystal devices.

9. Growth of ZnO Nanorods on GaN using Aqueous Solution
L.H. Quang, L.P. Koh and S.J. Chua

Semiconductor Nanostructure has become one of the most intensively studied subjects over the last few decades because of their potential application in electronic and photonic devices. Many materials such as Si, GaAs, InN and GaN have been grown into nanostructures. Among these, ZnO is of particular interested because of its novel properties: unique material exhibiting semiconducting and piezoelectric dual properties, direct band gap and low cost.

The aqueous solution method has been used to fabricate ZnO nanorods. This method has some advantages compared with other method (MOCVD, MBE, pulse laser deposition) such as being a simple technique, low temperature deposition, low cost and being less hazardous. Using this method, the ZnO nanorods were obtained on GaN having polygon top surface , hexagonal cross section with diameter of 80-100nm and length of about 1um. All the nanorods were vertically aligned in the c-axis orientation, uniformly distributed all over the substrate. Photoluminescence measurement, Scan Electron Microscopy (SEM) and X-ray diffraction (XRD) measurements were used to characterize the optical properties, the surface morphology and crystalline properties of the nanorods.

10. Graded InGaN Buffers For Strain Relaxation
T.L. Song and S.J. Chua

Strain relaxation in InGaN/GaN epilayers grown on *c*-plane sapphire substrates was observed to decrease as the InGaN layer becomes thicker. The formation of V-pits was modeled through the energy balance between the strain energy in the InGaN epilayer, the destruction of dislocation energy to form V-pits and the strain that is relieved due to the formation of edges during the process of nucleating V-pits in thermal equilibrium. The model illustrates many features that correlate reasonably well with experimental observations; the most significant trends are a rise in V-pit density and a decrease in strain with increasing layer thickness. The model is also consistent with the conclusion that V-pits have a range of sizes in the final surface of InGaN/GaN, hence suggesting the presence of a strong driving force at a critical juncture upon surpassing a certain thermal barrier.

11. The Effect of the Mg Doped on InGaN/GaN Multiple Quantum Well
Z. Chen and S.J. Chua

The interest in GaN as a material for light emitting and electronic devices has caused many investigations on its physical properties. GaN is primarily of interest for its application as light emitting diode (LED) and Laser diode (LD). For that reason, much of the effort devoted to GaN has been directed towards determining or improving its optical properties.

In this presentation, the influence of the Mg doping on the characteristics of InGaN/GaN multiple quantum wells (MQWs) by means of photoluminescence (PL) and atomic force microscopy (AFM) is presented. The four period MQWs were grown by metalorganic chemical vapor deposition. The PL measurements show that Mg doping results in stronger emission, narrower linewidth and less blueshift with the increased excitation intensity. Screening the valence band bending due primarily to piezoelectric and spontaneous polarization is attributed to these effects. There results show that the Mg doping could improve the optical properties of the GaN photon devices. The AFM measurements indicate that Mg doping results in better surface morphology properties of the MQWs. The density of the V-defect was observed to decrease from ~$10^9/cm^2$ (undoped) to $10^6/cm^2$, further to 0 with increasing Mg doping concentration.

12. Growth of GaN on Silicon
K.Y. Zang, L.S. Wang and SJ Chua

Growth of GaN on silicon substrates offers the very attractive potential of incorporating GaN devices onto silicon-based very large-scale integrated circuits. However, GaN has large lattice mismatch (17%) and large difference in thermal expansion coefficient (+100%) with silicon, which would induce the mismatch stress in GaN. Buffer layers are typically employed to adsorb and release the mismatch induced stress and to prevent the formation of such amorphous layer at the interface to achieve the good quality of GaN devices on silicon. The high temperature AlN layer is most commonly used as a buffer layer to achieve the high quality GaN on Si. There are a few reports on the high-quality GaN on Si (111) with AlN buffer layer by molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD). However, there are few investigations on the evolution of AlN buffer layer and its effects on the subsequent growth of GaN by metalorganic chemical vapor deposition (MOCVD). We will study the structural and morphological evolution of AlN buffer layers on Si (111) substrates, and the effect of the buffer thickness on the subsequent epitaxial GaN film grown by MOCVD.

13. Mechanism of stress reduction in GaN epitaxy on Si (111) by periodic silicon delta-doping
K.Y. Zang, L.S. Wang and S.J. Chua

Periodic silicon delta-doping technique in GaN epitaxy on Si (111) by metalorganic chemical vapor deposition has been investigated in this paper. It is found that as a result of periodic silicon delta doping, tensile stress and the density of threading dislocations are largely reduced and the quality of GaN film is improved as observed by x-ray diffraction, micro-Raman, atomic force microscopy and transmission electron microscope. A global energetic model has been applied to calculate the balance of the energy between the surface energy, the intrinsic strain energy and the grain boundary energy at the coalescence stage. The residual stress can be estimated with respect to the size of the GaN nuclei during coalescence. The results show that with larger size of GaN nuclei, smaller stress and lower dislocation density would be developed. With periodic silicon delta doping, the coalescence of GaN nuclei is delayed. By doing so, larger GaN grains were formed in the GaN film, which lead to less grain boundaries and less tensile stress. Other possible stress relaxation mechanism induced by delta doping of Si will also be discussed in the paper.

14. Fabrication of electroluminescent device with rare earth implanted porous Semiconductor
A. Prakesh, S. Tripathy and S.J. Chua

Porous semiconductors are widely studied materials due to the possible application in optoelectronics, in chemical and biochemical sensors, as a sacrificial layer in micromachining applications. Porous materials can also be used as buffer layers for epitaxial growth of SiC and GaN.
The efficiency of optical devices, e.g. LEDs and laser diodes, are restricted due to the lack of suitable substrate. Their lifetime and threshold current are limited due to the higher defects and dislocations, which act as non-radiative centers. Reduction in the defects and dislocations density in the material is essential to improve the performance of the optical devices. Pores might act as a sink for mismatch dislocations and accommodate elastic strain in hetrostructures; therefore porous materials are suitable for epitaxial regrowth of SiC and GaN.
The interesting feature of porous semiconductor is emission above the band gap of normal semiconductors. Porous semiconductors with wide band gap (GaN, AlN etc) are suitable for the deep UV application.
Porous silicon was the first semiconductor studied due to the emission in visible region. The thermal, chemical and mechanical property of porous silicon was not very good which limits large scale application. Due to lack of robustness of porous Si, III-V nitrides have been examined. The thermal, chemical and mechanical properties of GaN make it desirable material for optoelectronics.

15. 3D Photonic structures
X.S. Zhao, Q.F. Yan and SJ Chua

Optical transmission properties of electromagnetic waves propagating along [111] and [100] directions in none-close-packed opal-based photonic crystals have been investigated by using transfer matrix method (TMM). Comparing with close-packed opals, non-close-packed opal structures exhibit much stronger optical scattering due to their higher porosity. Theoretical calculations indicated that the dip in the transmission spectra is due to the splitting of the photonic bands in certain high symmetry points of the Brillouin zone. Numerical computation results showed that both the gap ratio and the mid gap frequency of the pseudogap along the main crystallographic directions such as [111] and [100] directions, which correspond to the L and X points of the Brillouin zone in reciprocal space respectively, increase with the decrease in dielectric filling ratio. The results agree well with the analysis of photonic band structure computed with plane wave extension (PWE) method, as well as the experimental data in the literature. Incidence-angle-dependent transmission spectra for none-close-packed opals were also obtained and exhibit a similar behavior with that of conventional close-packed opals.

16. Fabrication and Properties of Nanoporous GaN Films
Y.D. Wang, P. Chen and S.J. Chua

Nanopore arrays with pore diameters of approximately 75 nm were fabricated in GaN films by inductively coupled plasma etching using anodic aluminum oxide (AAO) films as etch masks. Nanoporous AAO films were formed on the GaN surface by evaporating an Al film onto a GaN epilayer and subsequently anodizing the aluminum. Scanning electron microscopy (SEM) analysis shows that the diameter and the periodicity of the nanopores in the GaN were directly transferred from the original anodic alumina template. The pore diameter in the AAO film can be easily controlled by tuning the anodization conditions. Atomic force microscopy (AFM), photoluminescence (PL) and micro-Raman techniques were employed to assess the etched GaN nanopore surface. This cost-effective, non-lithographic method to produce nano-patterned GaN templates is expected to be useful for growth and fabrication of nitride-based nanostructures and photonic bandgap materials.

17. Defect study of GaN and its Quaternaary Alloy.
C.B. Soh and S.J. Chua

GaN based III-V semiconductors have attracted intense interest due to their tremendous applications for short wavelength as well as blue light emitting diodes and lasers. Despite the progress made in device fabrication, the role of the various defects in GaN and their effect on the device performance has not been well understood. Surface pits, threading dislocations and deep levels have detrimental impact on the electrical and optical properties of the device fabricated. High yellow band emission, series resistance and leakage are some of the common flaws associated with the defects in the GaN. In this presentation, the contribution of the deep levels to yellow luminescence and its origin will be studied. The effect of surface pits on luminescence of the quaternary and ternary alloy will also be discussed.

18. Organic light-emitting devices
L. F. Liew, F.R. Zhu and S. J. Chua

The project focuses on the fundamental research and development of efficient and durable organic light-emitting devices (OLEDs), with emphasis on the improvement of interfacial properties for enhanced OLED performance. The scope of this proposal includes (a) identifying the origins of the dark spots formation and developing techniques for optimizing device structure and (b) understanding better the intrinsic degradation mechanism in OLEDs and engineering interfacial properties to obtain a balanced carrier injection system for efficient and durable OLEDs.

The degradation of the OLED often correlates the formation of the dark spots in the active area of the devices. The growth of the dark spots can usually be observed when the devices are under the bias. In order to study the origins of the dark spot formation in OLEDs, an optical image analysis is proposed to study the growth of the dark spots formed in OLED without the bias. This technique helps to identify and monitor the growth of the dark spots under desired device process condition. This approach avoids the complexity of the growth of dark spots influenced under electrical field. The preliminary results indicate that the growth of dark spots depends on the organic layer thickness and the contact between anode and first organic layer.

19. Ion channeling studies: Development and applications in semiconductor device technology
T. Osipowich, M.A. Rana,, H.W. Choi, M.B.H. Breese, S.J. Chua and F. Watt

Annealing experiments were carried out on GaN layers which were grown on sapphire using Metal Organic Chemical Vapour Deposition (MOCVD). The samples were annealed at temperatures between 500 and 1100 °C for a time interval of 60 seconds. Rutherford backscattering spectrometry (RBS) was performed on as-grown and annealed GaN samples using 2 MeV proton to study the effects of annealing on GaN crystalline quality and stoichiometry. No decomposition was measured for temperatures up to 800 °C. Decomposition in the near-surface region increased rapidly with a further increase in temperature, resulting in a near-amorphous surface-region for annealing at 1100 °C The depth profiles for nitrogen and incorporated oxygen in the decomposed GaN are extracted from the nanoscale RBS data from different annealing conditions. The surface roughness of GaN layers observed by atomic force microscopy (AFM) is consistent with decomposition measurements using RBS. We describe the range of annealing conditions under which negligible decomposition of GaN is observed, which is important in assessing optimal thermal processing conditions of GaN. In this project ion channeling is used to study lattice disorders (defects and impurities etc.) and lattice mismatch at interfaces

20. Alignment of self-organized InAs QDs on InP/GaAs and GaAs/InP substrate by MOCVD
B.Z. Wang and Prof S. J. Chua

Self-organized growth of InAs QDs on an InP/GaAs substrate by MOCVD has been investigated. A 2-degree-off GaAs (001) vicinal substrate, and TMGa, TMIn, TBA and TBP were used in the experiments. An InP layer with thickness of ~ 8 MLs and ~ 16 MLs was first deposited on the GaAs substrate followed by an InAs layer with thickness of ~ 3 MLs and 6 MLs deposited at different growth temperatures. Well alignment of dot-like, bar-like and wire-like structures was observed by AFM. The experimental results showed that the shape and alignment of the nano-structures depend on the thickness of the InP and InAs layers as will as growth temperatures. The nano-structures coved by a thin GaAs layer were also investigated.

In addition, the experimental results of InAs islands grown on a GaAs/InP (001) substrate as comparison are also presented, which were grown by MOCVD, using TMGa, TMIn, AsH3 and PH3 as source materials. Grid-patterned alignment of the InAs islands were formed on the GaAs layer that was grown on the InP (001) substrate with miscut < 0.5 degree. Very uniform InAs islands were obtained if a thin GaAs layer was used. However, big elongated InAs islands, besides small ones which were similar with that formed on the thin GaAs layer, were observed. Raman spectra were used to identify the strain of the GaAs layer which played an important role for positioning and shaping the InAs islands. The possible mechanisms involved in the ordering and shaping of the structures of the InAs islands formed on the GaAs/InP substrate, which are different with that formed on a vicinal InP/GaAs substrate, are discussed.

3. MAJOR EQUIPMENT

During the year the following pieces of equipment were installed/set up

Upgrading of X'Pert Epitaxy 4.0 process control software for MRD X-rays system.

The Mass Flow Controller (MFC) and Gas Reactor column has been installed.

The EPI-Unibulb-Nitrogen RF-Plasma cell has been installed.

The New RF power generators and Mechanical Pump for ICP system have been installed.

4. COLLABORATIONS WITH INDUSTRY AND INSTITUTIONS

Confidential Projects

To achieve one of its aims of serving as a resource centre for industry, the Centre has been active in seeking collaboration with industry and other institutions. For confidential reasons, companies are not named and projects that are still active are listed below.

1. Development of high frequency heterojunction bipolar transistors.
2. Fabrication of high power GaAs FET and MMIC components.
3. Mirror coating of InGaAlP LEDS.
4. Photoexcitation decay of InGaAlAs grown by MBE at low temperatures.
5. InP Based Heterojunction Bipolar Transistors.
6. Development of Fabrication Processing Technologies for Semiconductor LEDs

Non-Confidential Projects

1. RBS and Channelling Contrast Microscopy on GaN layers were carried out jointly with the Department of Physics, NUS.

2. III-V compound semiconductor characterisation using Transmission Electron Microscope and Cathodoluminescence measurement are in progress with the Characterization Programme of IMRE.

3. Measurement of Piezo-electronic field using TEM in InGaN QW in collaboration of Cambridge University.

COE provided services to a number of organisations, which are listed below:

MBE Technology Pte Ltd,

The Institute of Microelectronics,

The Institute of Materials Research & Engineering and

Data Storage Institute.

Fujitsu Quantum Devices

Sumitomo Electric Industries

Tinggi Technologies Pte Ltd

COE is conducting Research Training Program (RTP) in Optoelectronics which is co-funded by A*STAR and EDB.
Under this program, COE has trained following 9 Engineers during the year 2001-2002 , 2002-2003 and 2003-2004 respectively.

1. Mr.Huang Dong Hao, M.Sc., Beijing University, PRC
2. Mr.Liu Da Wei, B. Eng., Northwest Polytechnics Industrial University, PRC
3. Mr.Wang Yan Jun , B. Eng., Huazhong University of Science and Technology, PRC
4. Mr.Du Yuan Min, B. Eng., Nanjing University, PRC
5. Mr.Li Heyin, Ph.D.., Fudan University, PRC
6. Mr.Li Weigang, M.Sc., Beijing Normal University, PRC
7. Mr.Wu Yongjian , M.Sc., Fudan University, PRC
8. Mr. Zhang Lianwen, M.Sc., Sichuan University, PRC
9. Ms. Ruchi Agrawal, B.Sc., Nanyang Technological University, Singapore

6. SHORT COURSES AND SEMINARS

Key Note Speaker/Report **–by staff**

1. Key Note speaker on the topic " Quantum Dots and Group III-Nitride Optoelectronics" by **Professor Chua Soo Jin** for 1st Nanoengineering and Nanoscience Congress, 7-9 July 2004, Singapore.

2. "Nanotechnology" report presented by **Professor Chua Soo Jin** in Asia nanotech Forum Summit 2004, 10-11 April, Phuket, Thailand.

Invited Seminars:

1. "Electro-Optical Switching in SiGe/Si Waveguide Devices", Invited speaker for 1st International Conference on "Group IV Photonics (GFP)", 29 September-1October, 2004, Hong Kong.

2. Invited speaker for Institute Electro-Optical Engineering Special Seminar Series, National Taiwan University, 3 May 2004 Taipei, Taiwan, ROC.

INTERNAL SEMINARS –by Staff and Postgraduate Students

1. **Graded InGaN Buffers For Strain Relaxation**
   Mr. Song Ting Lok **30 March 2004**

2. **Long Wavelength Laser Diode(LD) fabrication process**
   Mr. Zhang Lianwen **30 March 2004**

3. **Fabrication of Porous Semiconductors**
   Mr. Agam Prakash Vajpeyi **7 April 2004**

4. **The Effect of Mg Doped on InGaN/GaN Multiple Quantum Well**
   Dr.Chen Zhen **29 April 2004**

5. **Micro-Structural and Morphological Aanalysis of AlN Nucleation Layers Grown by MOCVD on Si (111)**
Ms Zang Keyan **18 May 2004**

6. **Improve Sunken Contacts in AlGaN/GaN HEMT**
Mr. Wang Haiting **18 May 2004**

7. **Defect Study in GaN and its Quaternary Alloy**
Mr Soh Chew Beng **8 June 2004**

8. **Fabrication and Properties of Nanoporous GaN Films**
Mr. Wang Yadong **8 June 2004**

9. **A Low-Leakage Low Temperature (S/D) Anneal (700 ˚C 30 s) nMOSFET using Substitutional $Si_{1-y}C_y$**
Mr. Tan Chung Foong **29 June 2004**

10. **Analysis of InP/InGaAs based MEMS structures**
Ms Ruchi Agrawal **29 June 2004**

11. **Growth of ZnO Nanorods on GaN using Aqueous Solution**
Mr. Huang Le Hong **17 August 2004**

12. **Synthesis of GaN nanowires using Pulsed Laser Ablation Method**
Ms Ng Keh Ting, Doris **21 September 2004**

13. **Metal Contacts to p-type Gallium Nitride**
Ms Lim Woon Chi, Janis **21 September 2004**

14. **Fabrication and Characterization of AlGaN/GaN High Electron Mobility Transistor**
Mr. Liu Chang **9 November 2004**

15. **Self-Assembly Approach to 3D Photonic Crystals**
Dr.Yan Qingfeng **9 November 2004**

16. **Two-dimensional Photonic Crystals Fabricated by Nano-imprint Lithography**
Mr. Chen Ao **23 November 2004**

17. **Nanosphere lithography and its application**
Mr. Wang Benzhong **23 November 2004**

CONSULTING –by Staff

1. MBE Technology Pte Ltd. – Quaternary growth by MBE of InGaAlAs.
2. Quaestus Singapore Pte Ltd – LED device fabrication and III-V Compound semiconductors
3. Shott Glass Singapore – Glass based Optoelectronics applications.
4. Philips Singapore Pte Ltd- LED degradation

7. VISITORS

Many visitors have come by the Centre and met with the academic staff for discussions on research and exchange of ideas. A number of the visitors are highlighted below:

Professor Sir Richard Friend,
FRS, FREng
Cavendish Laboratory, Madingley Road
Cambridge CB3 OHE — 28 January 2004 Wednesday

16 visitors from Trisakti University,
Indonesia — 28 Feb 2004 Saturday

1. **Professor Wei HUANG**,
Director-General, Institute of Advanced Materials (IAM),
2. **Mr. Qianghua SHI**,
Director, Department of Basic Research,
Commission of Science and Technology of Shanghai Municipality.
3. **Professor Wei WEI**,
Head, Department of Information Technology,
National Natural Science Foundation of China (NSFC).
4. **Professor Qingyuan JIN**,
School of Information Science and Technology, Fudan University.
5. **Professor Shiming ZHOU**,
Department of Physics, Fudan University. — 16 March 2004 Tuesday

Dutch Vacuum Society group (25 peoples) — 7 May 2004 Friday

Prof Ruediger Vahldieck
Laboratory for Electromagnetic Fields and Microwave Electronics (IFH)
Swiss Federal Institute of Technology (ETH) Zurich
Switzerland — 10 May 2004 Monday

Dr Ye Yonghong
postdoctoral associate.
Center for Nanoscale Science,
Pennsylvania State University, U.S.A — 3 June 2004 Tuesday

Dr Martin Ang
Senior Research Engineer
Singapore Institute of Manufacturing Technology (SIMTech)
Singapore — 10 June 2004 Thursday

8. VISITS TO FOREIGN INSTITUTES AND INDUSTRY

During the past year, members of staff visited foreign institutions to give seminars, lectures and to establish links.

1. Prof. SJ Chua
   Singapore-UCSB Nanoscience and Nanotechnology Workshop
   Santa Babara, USA — 19-21 Apr 04

2. Prof. SJ Chua
   Asia Nanotechnolgy Forum
   Phuket, Thailand — 9 - 12 May 04

3. Prof. SJ Chua
   R & D Seminar
   Graduate Institute of Electro-Optical Engineering
   College of Egineering and Computer Science
   Taiwan National University — 23 - 25 May 04

4. Prof. SJ Chua
   SMA Summer Conference
   MIT, Boston, USA — 1 - 5 Aug 04

5. Prof. SJ Chua
   Croucher Advanced Study Institute on "Frontiers of Photonics Research"
   Chinese University of HongKong — 4 - 10 Dec 04

9. PUBLICATIONS

Patents, Publications List for Centre for Optoelectronics(COE)

January 2004 – December 2004

Patent Licensed

1. Chua SJ and Li BJ, High carrier injection optical waveguide switch – Suitable for 1.3 μm and 1.55 μm wavelength range for 2 inputs and 2 outputs. Issued 14th October 2003, Patent No US6,633,692 B2.

Patents Granted

1. Chua Soo Jin, Mark Auch, Ewald Guenther, **Procedure for encapsulation of electronic devices,** date granted 12 Oct 04, USA Patent No. :6803245

2. Teng JH, Chua SJ and Dong JR, **Method for forming a modified semiconductor having a plurality of bandgaps.** Singapore patent application No. 2002 02027-9**.** Date granted: 27 February 2004

Patents Filing

1. Chua SJ, Chen Peng, Wang YaDong, **Nanostructures And Method Of Making The Same,** Ref 200329; filed on 31 August 2004.

2. Teng JH, Chua SJ, Dong JR, **Distributed feedback and distributed Bragg Reflector Semiconductor Lasers with dielectric grating"**
Ref: 200328; filed in Singapore 4 Aug 04

Publications (Jan 2004 – December 2004)

International Refereed Publications

1. LS Wang, S. Tripathy and SJ Chua, "Effects of periodic delta-doping on the properties of GaN:Si films grown on Si (111) substrate." **Appl. Phys. Letts.,** Vol. 85, No. 24, pp. 5881 – 5883, 2004
2. M. E. Loomans, D. Z. Chi and S. J. Chua, "Monosilicide-desilicide-silicon phase equilibria in the nickel-platinum silicon and nickel-palladium-silicon systems", **Metallurgical and Materials Transactions A**, Vol 35A, No 10, pp. 3053-3061, (2004)
3. P Chen, S J Chua, Z L Miao, "Phase separation in AlGaN/GaN heterojunction grown by metalorganic chemical vapor deposition", **Journal of Crystal Growth,** Vol 273 No 1-2 pp 74-78, (2004)
4. BJ Chen, XW Sun, BK Tay, L Ke and SJ Chua, "Improvement of efficiency and stability of polymwer light-emitting devices by modifying indium tin oxide anode with ultrthin tetrahedral amorphous carbon film", **Appl. Phys. Letts**., Vol. 85, No. 12, pp (2004)

5. YX Jie, ATS Wee, CHA Huan, WX Sun, ZX Shen and SJ Chua, “Raman and photoluminescence properties of Ge nanocrystals in silicon oxide matrix”, **Matls. Science and Engineering,** vol. B107, pp. 8 – 13, (2004)
6. BJ Li, SJ Chua, EA Fitzgerald, BS Chaudhari, S Jiang and ZG Cai, “Intelligent integration of optical power splitter with optically switchable cross-connect based multimode interference principle SiGe/Si”, **Appl. Phys. Letts**., Vol. 85, No. 7, pp.1119 – 1121, 2004
7. HR Yuan, JR Dong, SJ Chua and YJ Wang, “Metalorganic vapor phase epitaxy growth of AlGaInAs quantum dots on (100) GaAs substrate”, **J. Crystal Growth,** vol 270, pp. 50 -56, 2004
8. S. K. Donthu, D. Z. Chi, S. Tripathy, A. S. Wong and S. J. Chua, Ramam scattering probe of anharmonic effects in NiSi, **J. of Ramam Spectroscopy** Vol 35 No 7 pp 536-540, 2004
9. S. K. Donthu, S. Tripathy, D. Z. Chi and S. J. Chua,” Micro-Raman spectroscopic investigation of NiSi films formed on BF2+, B+ and non-implanted (100)Si substrates”, **Applied Physics A**: Materials Science and Process, Vol 79 No 3, pp 637-642, 2004
10. Y.F. Liew, F. R. Zhu and S.J. Chua, “Effect of organic layer combination on dark spot formation in organic light emitting devices”, **Chemical Physics Letts**, vol. 394, pp. 280 – 284, 2004
11. Y.F.Liew, F.R.Zhu and S.J. Chua, “Alq3-modified indium tin oxide for enhancing the efficiency and reliability of organic light emitting devices” **Appl. Phys. Letts**. Vol. 85, No. 19, pp. 4511 -4513, 2004
12. HR Yuan, SJ Chua, ZL Miao, JR Dong and YJ Wang, Growth and structural properties of thick InAs films on GaAs with low-pressure metalorganic vapor phase epitaxy, **J. Crystal Growth,** vol. 273, pp 63 – 67, 2004
13. S. Tripathy, T. Htoo and S.J. Chua, “Influence of substrate misorientation on vibrational properties of $In_{1-x-y}Ga_xAl_yAs$ grown on InP”, **J. Vac. Sci. Technology**., Vol. A22(1), pp. 111-116, (2004)
14. YD Wang, SJ Chua, MS Sander, P Chen, S. Tripathy and CG Fonstad, “Fabrication and properties of nanoporous GaN films, **Appl. Phys. Letts**. Vol.8, No. 5, pp. 816 – 818, 2004
15. C.X.Xu, X.W. Sun X.H. Zhang, L. Ke and S.J. Chua, “Photoluminescent properties of copper-doped zinc oxide nanowires”, **Nanotechnology**, pp. 856 -861, 2004
16. C.X. Xu, X.W. Sun, Z.L. Dong, M.B. Yu, T.D. My, X.H. Zhang, S.J. Chua and T.J. White, “Zinc oxide nanowire and nanorod fabricated by vapor-phase”, **Nanotechnology**, vol. 15, issue 7, pp. 839 – 842, 2004
17. C.K. Chia, Z.L. Miao, Y.H. Chye and S.J. Chua, “Enhanced photoluminescence intensity for InAs self-assembled quantum dots grown by MBE using ‘nucleation-augment’ method”, **Appl. Phys. Letts.** Vol. 85, No. 4, pp. 567 -569, 2004
18. X.C. Wang, G.C. Lim, HY Zheng, F.L. Ng, W. Liu and S.J. Chua,”Femtosecond pulse laser ablation of sapphire in ambient air”, **Appl. Surf. Sci.**, vol. 228, pp. 221-226, 2004
19. K.Y Zang, LS Wang, SJ Chua and CV Thompson, “Structural analysis of metalorganic chemical vapor deposited AlN nucleation layers on Si(111)”, **J. Crystal Growth,** Vol. 268, 3-4, pp. 515 – 520, 2004
20. Z.L. Miao, S.J. Chua, S. Tripathy, CK Chia, YH Chye and P Chen, “High quality InAs grown on GaAs substrate with an in-situ micro-structured buffer”, **J. Crystal Growth**. Vol. 268, pp18 -23, 2004
21. C.B. Soh, S.J. Chua, H..F Lim, D.Z. Chi, S. Tripathy and W. Liu, Assignment of Deep Levels causing Yellow Luminescence in GaN, accepted for **J. Appl. Phys.**, vol. 96, No. 3, pp. 1341 -1347, 2004
22. C. B. Soh, W. Liu, S. J. Chua, S. Tripathy, D. Z. Chi,” Inverted hexagonal pits formation in AlInGaN epilayer”, **J. Crystal Growth**, Vol. 268, No 3-4, pp 478-483, 2004

23. CB Soh, SJ Chua, HF Lim, DZ Chi, W Liu and S Tripathy, "Identification of deep levels in GaN associated with dislocations", **J. of Phys. : Condens. Matter,** vol. 16, pp. 1 - 11, 2004
24. K. S. Low, J. H. Teng, S. J. Chua, "Simulation of 1.55 um distributed feedback semiconductor laser: investigation of dielectric grating yielding high coupling effect", **J. Crystal Growth**, Vol 268 No 3-4, pp 437-443, 1 Aug 2004
25. C.Y. Liu, Shu Yuan, JR Dong, SJ Chua, "Temperature dependence of photoluminescence intensity from AlGaInP/GaInP multi-quantum well laser structures", **J. Crystal Growth,** Vol. 268, 2-3, pp. 426 -431, 2004
26. J.R. Dong, J.H. Teng, S.J. Chua, B.C. Foo, Y.J. Wang, L.W. Zhang, H.R. Yuan. Continuous-wave operation of AlGaInP/GaInP quantum-well lasers grown by metalorganic chemical vapor deposition using tertiarybutylphosphine, **J. Appl. Phys**, vol. 95 (9), pp. 5252-5254, 2004
27. J.R. Dong, X.H. Zhang, S.J. Chua, Y.J. Wang, "Photoluminescence of compressively strained AlGaInP/GaInP quantum well structures grown by metalorganic chemical vapour deposition", **J. Crystal Growth,** Vol. 266, pp. 449 – 454, 2004
28. J.R. Dong, S.J. Chua, Y.J. Wang and H.R. Yuan, "Substrate orientation dependence of In composition of AlGaInP epilayers grown by MOCVD", **J. Crystal Growth,** Vol 269, pp 408-412, 2004
29. X. H. Zhang, W. Liu, S. J. Chua, "Optical transitions in InGaN/GaN quantum wells: effects of the piezoelectric field", **J. Crystal Growth**, Vol. 268 No 3-4, pp 521-526 2004
30. X. H. Zhang, J. R. Dong, S. J. Chua, J. Zhang, Anna Yong, "Metalorganic chemical vapor deposition and spontaneous emission of self-assembled InAs quantum dots in open space and in planar microcavity", **J. Crystal Growth**, Vol. 268, No 3-4, pp 420-425, 2004
31. S. J. Xu, Q. Li, J. R. Dong and S. J. Chua, "Interpretation of anomalous temperature dependence on anti-Stokes photoluminescence at GaInP2/GaAs interface", Applied Physics Letters Vol 84 No 13 pp 2280-2282, 29 Mar 2004
32. HO Chaw, KL Pey, CH Tung, BC Zhang, KC Tee, G. Karunasiri and SJ Chua, Uniform void-free epitaxial CoSi2 formation on shallow-trench-isolation bounded narrow Si (100) lines by template layer stress reduction" **Electrochemical and Solid-State Letts**. Vol. 7, no. 11, pp. H49 – H51, (2004)
33. T. Yuan, SJ Chua and YX Jin, "Calculation of the R_0A product in n^+-n-p and p^+-p-n GaInAsSb infrared detectors", **Infrared Phys. and Tech**., Vol 45, No. 3, pp 181-189, (2004)
34. XH Zhang, W Liu, SJ Chua, "Optical transitions in InGaN/GaN quantum wells: effects ofthe piezoelectric field", **J. Crystal Growth,** vol. 268, pp. 521 – 526, 2004
35. W. Liu, S.J. Chua and X.H. Zhang, "Determination of the Direction of Piezoelectric Field in InGaN/GaN Multiple Quantum Well Structures Grown by Metal Organic Chemical Vapour Deposition" **J. of Electronic Matls**. Vol. 33, No. 8, pp 841 - 845 (2004)
36. W. Liu, C. B. Soh, P. Chen, S. J. Chua, " Characterisation of AlInGaN quaternary epilayers grown by metal organic chemical vapor deposition", **J. Crystal Growth,** Vol. 268, No 3-4, pp 509-514, 2004
37. YB Zheng, SJ Chua CHA Huan and ZL Miao, "Growth of InAs quantum dots on shallow spherically shaped craters prepared on GaAs (001) substrates: an extended set of vicinal surfaces", **J. Crystal Growth,** Vol. 363, pp. 161 -166, 2004
38. T.L. Song, S.J. Chua and E.A. Fitzgerald, P. Chen and S. Tripathy, "Characterisation of graded InGaN/GaN epilayers grown on sapphire", **J. Vac. Sci. Technol**. A 22(2), pp 287-292, (2004)
39. SY. Xie, SF. Yoon, SZ Wang, ZZ. Sun, P. Chen and SJ Chua, "Influence of Be on N composition in Be-doped InGaAsN grown by RF plasma-assisted molecular beam epitaxy", **J. Crystal Growth**, Vol. 260, pp. 366-371, (2004)

40. L Ke, RS Kumar, K Zhang, SJ Chua and ATS Wee, “Organic light emitting device performance improvement by inserting a thin parylene layer”, **Synthetic Metals**, Vol. 140, No. 2-3, pp. 295-299, (2004)
41. L Ke, RS Kumar, K Zhang, SJ Chua and ATS Wee,”Effect of parylene layer on the performance of OLED”, Microlectronics Journal, vol. 35, No. 4, pp. 325 – 328 (2004)
42. L. S. Wang, S. Tripathy, W. H. Sun and S. J. Chua, “Micro-Raman scattering in Si-, C-, Mg-, and Be- implanted GaN layers”, **Journal of Ramam Spectroscopy**, Vol 35, pp 73-77, (2004)
43. H.W. Choi, PR Edwards, C. Liu, CW Jeon, RW Martin, IM Watson, MD Dawson, S. Tripathy and SJ Chua, “Sub-micron InGaN ring structures for high-efficiency LEDs”, **Phys. Stat. Sol. (c),** Vol. 1, PP. 202 -205, (2004)
44. S.Y. Xie, S.F. Yoon, S.Z. Wang, Z. Z. Sun, P. Chen and S.J. Chua, “Influence of Be on N composition in Be-doped InGaAsN grown by RF plasma-assisted molecular beam epitaxy”, **J. Crystal Growth**, Vol 260, Pg 366-371, 2004.
45. H.T. Wang, L.S. Tan and E.F. Chor, “Optical and electrical characterization of annealed silicon-implanted GaN,” **Semiconductor Science and Technology**, Vol.19, No. 2, pp.142-146, (February 2004).
46. L.K. Li, L.S. Tan and E.F. Chor, “Effects of surface plasma treatment on n-GaN ohmic contact formation,” **J. Crystal Growth**, Vol.268, pp.499-503, (2004).
47. H.T. Wang, L.S. Tan and E.F. Chor, “Study of activation of beryllium implantation in gallium nitride,” **J. Crystal Growth**, Vol.268, pp.489-493, (2004).

Conference Publications

Conference Papers 2004

1. S. J. Chua, “Quantum dots and Group-III nitride optoelectronics”, 1st Nano-Engineering & Nano-Science Congress 2004, 7 - 9 July 2004

2. C. K. Chia, S. J. Chua, Z. L. Miao and Y. H. Chye, “InGas self-organised quantum dots grown by molecular beam epitaxy using "nycleation-augmented method", 1st Nano-Engineering & Nano-Science Congress 2004, 7 - 9 July 2004

3. X. C. Wang, G. C. Lim, W. Liu, S. J. Chua, H. Y. Zheng, F.L. Ng, “Investigatinon on Femtosecond pulse laser processing of GaN on sapphire, Proceedings of the 1st Pacific International Conference on Application of Lasers and Optics 2004 (PICALO 2004) organized by Laser Institute of America, April 19-21, 2004. Melbourne, Australia, *Edited by Milan Brandt and Erol Harvey*

4. X. C. Wang, G. C. Lim, H. Y. Zheng, J. L. Tan, W. Liu, S. J. Chua, F. L. Ng, “248 nm excimer-laser-induced native oxide film formation on GaN surface, Proceedings of the 1st Pacific International Conference on Application of Lasers and Optics 2004 (PICALO 2004) organized by Laser Institute of America, April 19-21, 2004. Melbourne, Australia, *Edited by Milan Brandt and Erol Harvey*

5. RS Kumar, SJ Chua, K Lin, M. Auch, ..MRS Spring Meeting April 12-16, 2004, Moscone West and San Francisco Marriot, San Francisco, California

6. Z.C. Feng, Y.J. Sun, L.S. Tan, S.J. Chua, J.W. Yu, J.H. Chen, C.C. Yang, P-type doping in GaN through Be implantation, International Workshop on Nitride Semiconductors July 19 - 23, 2004, Sheraton Station Square, Pittsburgh, Pennsylvania, USA; Abstract due 3-17-2004

7. Z.C. Feng, W. Liu, S.J. Chua, J.H. Chen, C.C. Yang, Recombination Mechanism of InGaN Multiple Quantum Wells Grown by Metalorganic Chemical Vapor Deposition, International Workshop on Nitride Semiconductors July 19 - 23, 2004, Sheraton Station Square, Pittsburgh, Pennsylvania, USA.

8. SJ Park, HB Lee, KH Paek, LS Wang , SJ Chua, JH Lee, and SH Hahm, Schottky Diodes Fabricated on Cracked GaN Epitaxial Layer Grown on (111) Silicon, International Workshop on Nitride Semiconductors July 19 - 23, 2004, Sheraton Station Square, Pittsburgh, Pennsylvania, USA.

9. D. Z. Chi, R. T. P. Lee, and J. J. Chua, Addressing Materials and Process-integration Issues of NiSi Silicide Process Using Impurity Engineering (invited paper), The Fourth International Workshop on Junction Technology, 16-17 March 2004, Shanghai.

10. K. Y. Lee, D. Z. Chi, S. J. Chua H. P. Sun and X. Q. Pan, Formation and Morphology Evolution of Nickel Germanides on Ge (100) under Rapid Thermal Annealing, MRS Spring Meeting 12-16 April 2004, San Francisco, USA

11. T. Sudhirajan and SJ Chua, Nanoscopic photoluminescence imaging of III-nitride nanostructures. International Conference on Advanced Materials and Processing, IIT Kharagpur, India, 6-8 Dec, 2004

12. S. K. Ramadas, S. J. Chua, L. Ke, X. B. He, A. Burden, Study of Water Vapour Transport Properties of Different OLED Package Designs, MRS Spring Meeting 12-16 April 2004, San Francisco, USA

13. J. H. Teng, S. J. Chua, L. Y. Miao, R. Yin, B. J. Li and E. A. Fitzgerald, A 3x2 Waveguide Switch Based on SiGe for C-Band Operation, Photonics Europe, 26- 30 April 2004, Strasbourg, France

14. S. Tripathy and S. J. Chua, Near-Field Scanning Photoluminescence Microscopy of InGaN/GaN Quantum Structures, Photonics Europe, 26- 30 April 2004, Strasbourg, France

15. CHELLAPPAN Vijila; BALAKRISNAN Bavani; Mark AUCH Dai Joong; Eric OU Chuan Whatt; CHUA Soo Jin Investigation of charge carrier mobility in electroluminescent polyflurorene-co-polymer MRS-S National Conference on Advanced Materials.6 August 2004.

16. CHEN Peng; CHUA Soo Jin; TRIPATHY Sudhiranjan; MIAO Zhong Lin; Rayson TAN Jen Ngee, High-quality GaN and InGaN MQWs on 2-inch silicon substrates The Fourteenth International Conference on Crystal Growth, 9-13 Aug 2004, Alpes Congres, Grenoble, France

17. SOH Chew Beng; CHUA Soo Jin, Defects and its impact on luminescence of GaN related LEDs , 5th APRU Doctoral Students Conference, University of Sydney. 9-13 August 2004.

18. SOH Chew Beng; LIU Wei; CHUA Soo Jin; TRIPATHY Sudhiranjan; CHI Dongzhi, Probing the 2-dimensional electron gas in AlInGaN/GaN heterostructure by photoluminescence spectroscopy, MRS Fall 2004, Boston, USA manuscript: 94714, E3.43 , Probing the 2-dimensional electron gas in AlInGaN/ GaN heterostructure by photoluminescence spectroscopy, submitted to Symposium E, has been accepted for the proceedings. MRS Fall 2004, Boston, USA 29Nov-3Dec 2004

19. WANG Lian Shan; TRIPATHY Sudhiranjan; CHUA Soo Jin Contact and improvement of crystalline cracking from GaN film grown on Si by metalorganic chemical vapor deposition, IUMRS-ICA 2004 (Taiwan)

20. Wilhelmi O, Shahrain Mahmood, Kong JR, Saw BT, Casse DBF, Heussler SP, HO Moser, Chen A, Wang BZ, Chua SJ, Hot Embossing of Micro and Nanoscale Devices, 3rd International Conference on Materials Processing for Properties and Performance (MP^3), Symposium for Advanced Moulding & Forming Technologies, Singapore from 24 - 26 November 2004.

21. Y.D.Wang, S.Tripathy, S.J.Chua*, C.G.Fonstad, Fabrication and characterization of GaN nanopillar arrays, MRS 2004 Fall, Boston, USA, 29Nov-3Dec 2004.