Ph.D. Projects (2003/2004)

AMM&NS programme

Two-Dimensional Photonic Crystals Designed for High Efficiency Light-Emitting Diodes

Student	:	Chen Ao
Thesis Advisor (Singapore)	:	Prof Chua Soo Jin
Thesis Advisor (MIT)	:	Prof Clifton G. Fonstad

Project Abstract :
Light extraction remains a bottleneck for high efficiency light-emitting diodes (LED's). Most of the light generated from a semiconductor LED is lost within the high dielectric materials due to total internal reflection (TIR). Recently the research on photonic crystals tends to provide a novel, effective and practical solution to this problem.

Photonic crystals are periodic dielectric structures that have so-called photonic bandgaps, which prohibit the propagation of photons having energies within the bandgap region. Specifically, two-dimensional (2D) photonic crystals have the ability to control in-plane light propagation and enhance extraction of light in the vertical direction. Furthermore, spontaneous emission within 2-D photonic crystals can also be facilitated according to quantum electrodynamics. Since fabrication of 2-D photonic crystals with micro- and nano- dimensions can be realized using current semiconductor processing techniques, they can be readily utilized to improve the efficiency for LED's.

In this project, 2-D photonic crystals will be designed, fabricated, characterized and integrated into LED's based on the material of AlGaInP. Theoretical computation will be performed to fine-tune the photonic band diagram of the 2-D photonic crystals for the wavelengths of interest. Nanoimprinting will be employed for the fabrication process, which is applicable for mass manufacturing. The final objective is to achieve external efficiency enhancement for AlGaInP current injection devices operating at the wavelength of 650nm.

Oblique Angle Deposition

Student	:	Chew Han Guan
Thesis Advisors (Singapore)	:	Assoc Prof Choi Wee Kiong & Assoc Prof Chim Wai Kin
Thesis Advisor (MIT)	:	Prof Eugene A. Fitzgerald

Project Abstract :
Oblique Angle Deposition has the ability to generate nanostructures relatively easily. By tilting the substrate during normal film deposition so that it is at an angle relative to the plane of the source rather than parallel to it, deposition of nanopillars can be achieved. It makes use of the in-plane self shadowing mechanisms present due to the size of nuclei being different so that larger nuclei will shadow smaller nuclei. During normal deposition, this effect is also present but the shadowing length is very much shorter than the diffusion length of an atom so film deposited will be conformal. However, by tilting the substrate, this effect can be enhanced so that it becomes dominant. Thus regions which are shadowed will have very little film growth due to the low flux whereas larger structures will be able to capture more flux.

By making use of this technique to deposit film on a patterned substrate fabricated using an Anodic Alumina Mask (AAM) it is in the hope that regular arrays of nanopillars can be deposited. It is obvious that films deposited via this technique will be of very different properties as compared to normal film. Subsequent research upon successful fabrication of such structures will be to characterize its electrical properties and find applications for such structures.

Strain Relaxation in $In_xGa_{1-x}N$/GaN Epilayers

Student	:	Haryono Hartono
Thesis Advisor (Singapore)	:	Prof Chua Soo Jin
Thesis Advisor (MIT)	:	Prof Eugene A. Fitzgerald

Project Abstract :
GaN is a direct wide band gap material that has attracted great interest in blue-green lasers while InGaN compounds have been used to fabricate highly efficient blue, green, amber, and red light emitting devices. Incorporation of both materials will lead to a broad range of wavelength emission. However, epitaxial GaN films contain a high density of defects primarily threading dislocations due to the large lattice mismatch and thermal expansion coefficient difference with the sapphire substrate. Majority of the threading dislocations in GaN-related materials have no driving force to glide. In spite of this, the strain in $In_xGa_{1-x}N$/GaN epilayers grown on *c*-plane sapphire substrates was observed previously to decrease as the $In_xGa_{1-x}N$ layer becomes thicker. An enormous driving force was found to present in nucleating V-pits for strain relaxation.

The objective of this project is to grow a high quality $In_xGa_{1-x}N$ layer with high percentage of In. A buffer layer will be inserted to reduce the V-pits formation in the $In_xGa_{1-x}N$ layer. The growth of this buffer layer will be investigated to get the optimum conditions at which a high quality $In_xGa_{1-x}N$ layer can be grown.

Ordered Nanoparticle Structures through Colloidal Self Assembly

Student	:	Koh Yaw Koon
Thesis Advisor (Singapore)	:	Assoc Prof Wong Chee Cheong
Thesis Advisor (MIT)	:	Prof W. Craig Carter

Project Abstract :
Self assembly is a promising route for fabrication of large scale periodic nanostructure. These assembled structures have very interesting optical properties depending on the periodicity of the structure and dielectric contrast of the materials. Photonic band gap,

analogous to the energy gap in semiconductors, can occur in these photonic crystals. Theoretical considerations have demonstrated that many useful photonic devices can be made with careful control of the defects in the structures. This provides the motivation for understanding the mechanism of self assembly and the control of the defects.

Colloidal self assembly methods are one of the most promising routes for getting ordered structures. It is a relatively simple method and can be easily implemented into the existing silicon based technology. In this project, we will look at the driving force for assembly at the fluid/solid boundary and derive a plausible model for defects formation in colloidal crystals. This will help enormously in making photonic crystals and devices. Experimentation will also be carried out to validate and improve the model.

Bonded Interconnect for 3D IC

Student : Leong Hoi Liong
Thesis Advisor (Singapore) : Assoc Prof Pey Kin Leong
Thesis Advisor (MIT) : Prof Carl V. Thompson

Project Abstract :

Even with the introduction of copper-based interconnects and ultra-low-k dielectric materials, interconnect delay will continue to dominate over gate delay in determining the overall speed of integrated circuits. To address the interconnect bottleneck caused by exponentially increasing total wiring lengths, new circuit design and technology paradigms are required. According to the International Technology Roadmap for Semiconductors, 3D interconnects may be one of the solutions. In this approach, integrated circuits are designed, laid out, and fabricated in 3 dimensions, instead of the current 2 dimensions provided by planar single-layer technology. Both the high strength mechanical attachment of device layers and the high-density electrical interconnection required for 3D circuits would be investigated through the use of a high density of metal-metal (Cu-Cu) bonds. Appropriately designed and laid out densely-interconnected device layers would significantly lower wiring lengths, and thus correspondingly reduced wiring delay.

Advanced Battery Materials

Student : Wang Cuiyang
Thesis Advisor (Singapore) : Assoc Prof Li Yi
Thesis Advisor (MIT) : Prof Gerbrand Ceder

Project Abstract :

The rapid growth of portable electronic equipment is driving the need for smaller and lighter rechargeable batteries. Although Li batteries already have the highest energy density of any battery system, the power and energy requirements of many new portable devices can not be met with the current choices for electrode materials. This project will investigate the use of amorphous metals for use as in rechargeable batteries. Because of their structure and morphology it is expected that they can result in batteries with superior power and energy density.

Micro-Batteries for Integration with Microelectronics

Student : Xia Hui
Thesis Advisor (Singapore) : Assoc Prof Lu Li
Thesis Advisor (MIT) : Prof Gerbrand Ceder

Project Abstract :

There is considerable interest to develop on-chip rechargeable batteries for distributed and back-up power. Thin-film rechargeable batteries have therefore gradually received attention as power sources to integrate into circuits or to individual circuit components. They have many potential applications as small power supplies for microelectronic devices, such as implantable medical devices, transdermal drug delivery systems, sensors, miniature rf transmitters, microelectromechanical devices, and CMOS, SRAM and DRAM backup.

One of rechargeable battery is lithium batteries which can be fabricated completely in the solid state by successive deposition of contacts, electrodes and an oxide electrolyte. This makes them ideal for integration with microelectronics.

This project will use pulsed-laser deposition (PLD) technique to fabricate thin film batteries and develop battery materials that can lead to high power and energy density. In this project, the influence of deposition parameters, materials selection, and stacking sequences on the formation of high performance microbattery will be investigated. The influence of process parameters of PLD will be studied by measuring stoichiometry, thickness, phase and structure (grain size and texture), and stress of the deposited films. Thin film electrochemical properties will be studied through open-circuit voltage, charge-discharge cycling, cyclic voltammetry, and impedance analysis. Computer modeling will be used in design of microbattery materials.

Silicided Metal Gate Transistor for Nano-CMOS Technology

Student : Yu Hongpeng
Thesis Advisors (Singapore) : Assoc Prof Pey Kin Leong & Assoc Prof Choi Wee Kiong
Thesis Advisors (MIT) : Prof Dimitri A. Antoniadis & Prof Eugene A. Fitzgerald

Project Abstract :

Reduction of the gate length and gate dielectric thickness in complementary metal oxide semiconductor (CMOS) transistors for higher performance and circuit density aggravates problems such as poly-silicon (poly-Si) gate depletion, high gate resistance, and dopant penetration from doped poly-

Si gate. To alleviate these problems in nanoscale transistors, there is immense interest in the replacement of the conventional poly-Si gate material with metal gate materials. A metal gate material not only eliminates the gate depletion and dopant penetration problems, but also greatly reduces the gate sheet resistance. Now, Ni(alloy)-silicided metal is a promising replacement material for traditional poly-silicon gate. The goal of this project is to study Ni alloy silicide/Ni alloy germano silicide on ultra-thin gate oxide and high-k dielectrics.

The initial grain structure and Ni alloy silicide/Ni alloy germano silicide forming recipe have strongly influence on the gate quality and property. The grain structure depends on the growth temperature, gas flow rate, time and seed layer. The following annealing process need further study to control Ge outdiffusion and layer inversion.

The initial and final grain structure will be studied using TEM, AFM and SEM. XRD Micro-Roman and SIMS will be used to characterize the material property. To obtain the work function of the metal gate is also one of objectives of this project.

Interfacial and Dielectric Properties of Epitaxial Gate Oxides for Nanoelectronics Applications

Student	:	Zheng Jianxin
Thesis Advisors (Singapore)	:	Assoc Prof Chim Wai Kin & Assoc Prof Choi Wee Kiong
Thesis Advisor (MIT)	:	Prof Gerbrand Ceder

Project Abstract :

Epitaxial gate dielectrics, with high permittivites (high-k), have been receiving recent attention due to concerns on the stability of the high-k dielectric-silicon interface for alternative gate dielectrics grown on silicon. In the literature, there have been studies on the heteroepitaxial growth of Y_2O_3, Gd_2O_3 and $SrTiO_3$ and $BaTiO_3$ (primarily the alkaline earth and perovskite oxides) on Si, Ge and GaAs. The potential of minimizing interfacial oxide formation, of obtaining sharp interfaces with low interface trap density and of achieving higher permittivities in crystalline dielectric structures are advantages of the heteroepitaxial growth process. However, there is still limited knowledge and fundamental understanding of the dielectric-silicon interface. The same concerns also apply to germanium-based MOS technology.

The objectives of this project are to investigate the interfacial and dielectric properties of epitaxial oxides grown on silicon and germanium substrates through first principles modelling/computation. Comparisons of the calculations with some experimental measurements may also be envisaged.