# NUSNNI FOCUS GROUPS

**FOCUS GROUP**: **Nanophotonics**

**FOCUS GROUP CHAIRS**: Prof Chua Soo Jin (ECE, FOE)

A/Prof Loh Kian Ping (Chemistry, FOS)

**Focus Group Information**

**1. Objectives & Planned Deliverables**

**Objectives:**

Design and fabrication of photonic bandgap waveguides and nanostructures such as quantum dots, nanorings, nanorod and nanowires for optoelectronic and data storage applications.

Impact: These devices will improve efficiencies in radiative recombination, light extraction, modulations and charge storage. The new structures will introduce functionalities through device integration.

**Deliverables:**

1) Scientific paper publications in high impact international journals
2) Nanophotonics Technical patents
3) Postgraduates training
4) Keynote/invited lectures and presentations in International Conferences

**2. Research Plan & Focus**

**Research Plan:**

1. Growth of single crystalline ZnO nanorods and application in optoelectronic device.
2. Tailoring of MBE grown InAs quantum dots on GaAs for use in broadband light sources.
3. Nano-heteroepitaxy of GaN on Si to reduce strain and dislocation density in GaN epitaxial film.
4. Fabrication of Ge nanocrystal in Silicon dioxide matrix
5. Fabrication of 2-D and 3-D photonic crystal heterostructures using polystyrene nanoparticles.
6. MBE grown InAsN quantum wells for light emission at 1.3 to 1.5 μm wavelength for optical communication applications.
7. Fabrication of colloidal ZnO nano-particles for optoelectronic applications

**Focus:**
Design and fabrication of photonic bandgap waveguides, nanostructures materials growth and processing. (e.g. To develop the Photonic crystal membrane laser.

To fabricate semiconductor nanoparticle structures and to investigate methods for their ordering, size and shape control. To investigate the optical properties (i.e., electroluminescence and photoluminescence) of the fabricated semiconductor nanoparticle structures.

Fabrication of high quality ZnO nanorod arrays on GaN for making microlaser array.

**Grand challenge project:**

Light emitting Ordered ZnO nanorods and nanotubes

ZnO is a promising semiconductor with a large bandgap of 3.4 eV comparable to that of GaN and is useful for application in short wavelength light sources and high temperature electronics. An advantage of ZnO over GaN is the large exciton binding energy of 60meV, which would makes it a more efficient emitter. We have found a method of growing ZnO nanorod at low temperature using a solution technique. ZnO are also sputtered on thermally grown $SiO_2$ followed by annealing and also using electrodepositon through anodized aluminium oxide (AAO) template to create a ZnO seed for later growth by hydrothermal process.

One of the objectives of this project is to control the dimension and orientation of the nanorods by manipulating the reactant concentration, growth temperature and the pH.

As the lattice mismatch between ZnO and GaN is less than 2%, a heterostructure of GaN/ZnO can be formed with these rods to give efficient emitters. Locating these nano-size rods into an array will form a photonic bandgap crystal that enhances light extraction. The project aims to create a novel light source combining the photonic bandgap concept and efficient microcavity emission to yield very efficient light emitters.

Fabrication of semiconductor nano-structures and investigation of optical properties

Nanometer-sized semiconductor particles, or nanoparticles, have attracted much interest for the last two decades as they possess unique physical and optical properties that are closely related to their size. Semiconductor nanoparticles are expected to exhibit quantum confinement effects when their size becomes comparable to the Bohr exciton radius, which results in an increase in the energy gap relative to that of the bulk solid.

In many applications of nanostructured materials, such as microelectronics, optoelectronics and sensing, the ability to fabricate nanostructures with a high degree of regularity and uniformity is important in achieving tight control of their properties. Depending on the material, different nanostructure fabrication techniques are generally required. The template method is one commonly used approach to obtain ordered arrays of one-dimensional nanostructures. As a well-established nanotemplate, porous anodic alumina has been widely used to fabricate many kinds of nanowires and nanotubes, especially after the great improvement in pore regularity achieved using a two-step anodization process. Other methods for fabricating ordered arrays include electron beam lithography, nanoimprint, and self-assembly processes. However, there are fabrication and application restrictions for these methods, such as limited pattern area and low throughput, high equipment capital costs, and limited classes of materials that can be fabricated. In comparison, template methods are much cheaper, can be used to pattern large areas (several tens of square centimeters) of surfaces. Additionally, template methods allow for deposition of a wide range of materials.

At nanometer length scales, many new phenomena and physical properties are closely related to the shape and size of the nanoparticles, and thus the ability to vary these parameters is a key to realizing nanostructures with novel properties. Anisotropic optical and magnetic properties have been found in metallic nanorods, metallic nanoparticles, and metallic nanodiscs. Also, the luminescences of cadmium selenide semiconductor nanorods are strongly related to their shape. Nanoparticles of other shapes have also been fabricated, including cubic and triangular cadmium sulphide nanodots. Moreover, size is often a crucial nanostructure parameter. Some magnetic nanostructures show interesting properties as their size becomes comparable to certain fundamental length scales. For such reasons, good control of shape and size in nanoparticle fabrication has become one of the challenges in nanoscience and nanotechnology. We will be investigating methods for ordering, size and shape control in the fabrication of semiconductor nanoparticles (for example, nanocrystalline germanium, cadmium sulphide, indium oxide, etc.) and the effect on the optical properties of the resultant nanoparticle array structures.

There is also an interest in integrating group IV (i.e., silicon and germanium) nanoparticles/nanocrystals embedded in a silicon oxide matrix for applications in optoelectronics and photonics as this offers the advantage of compatibility with current silicon technology. Specifically, the interest is in the near-infrared (near-IR) communication wavelength region of 1.3 to 1.5 $\mu$m. Understanding the mechanisms, whether it is quantum confinement or defect related, that are responsible for the luminescent peaks is important as this could lead to directed efforts in improving the quantum efficiency of the light emission at these wavelengths. We will be investigating the near-IR electroluminescence (EL) of nanocrystalline germanium (Ge) embedded in silicon oxide, as there is relatively little work on EL (especially near-IR EL) as compared to photoluminescence (PL). Moreover, the biasing conditions under EL analysis will be closer to the operation condition of the nanocrystal photonic device. The Ge nanocrystals will be synthesized by partial oxidation of silicon-germanium ($Si_{0.54}Ge_{0.46}$) films, or sputtering, and high temperature annealing under different ambient. We will also be investigating the relation of nanocrystal quality to the optical performance (both EL and PL) of the nanocrystal devices.

Nitride and Arsenide semiconductor nanostructures

GaInAsN is a newly developed material system promising for long wavelength operation. Conventional GaInAs quantum well devices grown on GaAs substrate can only operate to maximum 1.2 μm wavelength. For telecommunication wavelengths, 1.3 and 1.55 μm, the conventional quantum well material is InGaAsP grown on InP substrate. However, InP-based materials have many disadvantages compare to GaAs-based materials such as poor temperature stability, expensive substrate cost, lack of good DBR (distributed Bragg reflector) materials, and so on. When incorporating nitrogen into GaInAs, the wavelength can be made longer, and increase with the incorporated nitrogen concentration. Thus it is possible to grow GaInAsN quantum wells on GaAs substrate for long wavelength applications. However, incorporating nitrogen into GaInAs is not easy, material quality degrades with the nitrogen incorporation. Our study on GaInNAs / GaAs quantum-well structures will help to understand the physics behind the optoelectronic device performance. the GaInAsN quantum dot structures will be studied. Optoelectronic devices such as semiconductor saturable absorbers applying the nitride semiconductor nanostructures will also be developed.
Further more, nanoscale GaAs on SiGe Heterogeneous material growth using MBE, Such as GaAs epilayers are grown by MEE on SiGe layers by control of growth rate, growth interruption times and temperatures are promising for the fabrication of CMOS devices.
Growth of GaN on porous Si obtained by electrochemical etching could provide low dislocation density and relaxed GaN and it is useful application for emission in the red wavelength.

**3. Websites of Affiliated Focus Group Members & Laboratories**

http://www.ece.nus.edu.sg/coe/
http://www.ee.nus.edu.sg/stfpage/elecsj/
http://www.chemistry.nus.edu.sg/ourpeople/academic_staff/lohkp.htm
http://www.imre.a-star.edu.sg/rnd/ResrchArea_OES.asp