Nanyang-DSO Graduate Programme (NDGP) 2024

By Temasek Laboratories @ NTU (TL@NTU) and DSO National Laboratories

Research Topics

The following are the research topics available for selection:

1. Fabrication and characterization of reliable III-Nitride high-electron-mobility transistors on novel substrates

Gallium nitride (GaN) based transistors will make up a large portion of the power electronics and the microwave electronics sectors in the very near future, replacing traditional materials such as silicon (Si) and Gallium Arsenide (GaAs). Because Gallium Nitride (GaN) based High-Electron-Mobility Transistors (HEMTs) can deliver the highest output power density and power added efficiency due to its inherent material properties such as wide band gap, high critical electric field and high electron velocities. As a result, these transistors are excellent for many important in both defense and commercial applications such as high-power and high-frequency operating monolithic microwave integrated circuits, electric vehicles, power grids, satellite communications, 5G/6G wireless communication and etc.

Currently, most GaN HEMTs are typically grown on Sapphire, Si and SiC substrates. However, due to the extremely high-power dissipation during operation, the performance and reliability of these transistors will deteriorate. Hence, new substrates with better thermal conductivity are needed to overcome these limitations. This project will involve the device layout design, device fabrication, device characterization, analysis of GaN HEMTs on novel substrates such as diamond, bulk GaN or AIN which could provide more efficient heat dissipation thus further enhance the performance and reliability of GaN HEMTs.

Supervisor: Prof Ng Geok Ing (EEE)
Co-Supervisor: Dr Subramaniam Arulkumaran (TL@NTU)

2. Design and Fabrication of III-Nitride high-electron-mobility transistors for 5G/6G Applications

Widebandgap semiconductor materials, such as Gallium Nitride (GaN), promise to revolutionise the world of microwave power amplifiers by providing high power density, linear operation and robustness up to mm-wave frequencies (30 to 300 GHz). New applications such as gigabit point-to-point 5G/6G wireless communications or automotive radar require mm-wave power amplifiers. Researchers have demonstrated improved power density using different III-Nitride alloys (e.g.: ternary, quaternary based heterostructures) by shrinking the fate (e.g.> 20 to 40 mm) fabrication processes.

Despite the great potential of these new technologies, they still suffer from physical and fabrication issues which may prevent devices fabricated on GaN and other III-Nitride alloys from achieving the improved device linearity and reliability levels requires. To improve the transistor linearity, it is required to design novel device structure, device simulation, device fabrication processes and its characterization. The main objective of this project is to explore different approaches to realize mm-wave operating devices by the optimization of device architecture design, device simulation, device fabrication and its electrical (DC, Pulsed I-V and RF) characterization.

Supervisor: Prof Ng Geok Ing (EEE)
Co-Supervisor: Dr Subramaniam Arulkumaran (TL@NTU)

3. GaN based HEMTs for high-power RF applications

Widebandgap semiconductor materials, such as Gallium Nitride (GaN), promise to revolutionise the world of microwave power amplifiers by providing high power density, linear operation, and robustness up to mm-wave frequencies (30 to 300 GHz). GaN-based high electron mobility transistors (HEMTs) have emerged as a promising technology for delivering high power at high frequency power amplifiers. This may lead to increase efficiency and reduce energy consumption. AlGaN/GaN-based HEMTs were studied extensively and demonstrated power densities up to 10 W/mm at 40 GHz. Beside their great promise, technological issues still impede the full exploitation of the potential foreseen for GaN-based devices. To push the power density, researchers have explored different approaches. For example, N-Polar GaN HEMTs, Multiple-Channel GaN HEMTs, AlN/GaN HEMTs, InAlGaN/GaN HEMTs, GaN-on-Diamond and etc…

The purpose of this work is to improve the present GaN-based HEMT technology, increasing device power density and its efficiency by the optimization of device architecture design (e.g. Multiple-Channel GaN HEMT or N-Polar GaN HEMT or GaN-on-Diamond), device simulation, deeply scaled device fabrication and its electrical (IV, Pulsed I-V, CV and RF) characterization.

Supervisor: Prof Ng Geok Ing (EEE)
Co-Supervisor: Dr Subramaniam Arulkumaran (TL@NTU)

4. Growth of nitrogen polar GaN HEMT for high-frequency and high-power applications

AlGaN/GaN high electron mobility transistors (HEMTs) have been developed for high-power and high-frequency electronic devices due to their high electron saturation velocity and high breakdown field. They are mostly fabricated on the Ga-polar orientation (0001) to achieve superior crystalline quality. However, N-polar orientation $(000\bar{1})$ has attracted greater interest in recent times due to its inverted polarity which offers strong electron confinement, low contact resistance, highly scaled devices with higher power density and better dispersion control. Record power density of 8 W/mm with over 28% power-added efficiency at 94GHz for metal-insulator-semiconductor HEMTs based on N-polar GaN have been recently reported.

Unlike Ga-polar epistructure, establishment of high-quality N-polar epistructure is challenging to realise high performance devices. The surface polarity, crystal quality and the coalescence of GaN depend on the nitridation condition, growth temperature and V/III ratio employed. This work aims to establish excellent quality HEMT epilayer heterostructures on SiC by investigating the effect of various growth parameters on the 2-dimensional electron gas properties. The surface, electrical, structural and optical properties of the grown layers will characterized using advanced tools such as AFM, Hall, CV, HR-XRD, SIMS and HR-TEM and the results will be correlated to growth parameters. The optimised epilayer structures will be utilized to demonstrate HEMT device characteristics.

Supervisor: Assoc Prof Radhakrishnan K. (EEE)
Co-Supervisor: Dr Dharmarasu Nethaji (TL@NTU)

5. Growth of AlN/GaN hetrostructure based HEMTs for high-frequency and high-power applications

Binary AlN/GaN HEMTs with stress-free barrier is attractive over competing AlGaN/GaN HEMTs for vertical and lateral scaling to achieve very high-frequency operation. When ultra-thin AlN barrier layer is employed, and is coherently grown on the underlying GaN, 2DEG densities as high as 2 – 6 x 1013/cm2 are realizable due to the maximum difference in polarization. In this work, the growth and characterization of AlN/GaN/AlN double heterojunction (DH) HEMT on semi-insulating 4H-SiC substrates will be investigated. The higher thermal conductivity of AlN and 4H-SiC is expected to improve heat dissipation, thus providing greater thermal stability and lesser deterioration due to self-heating. The AlN/GaN/AlN DH-HEMT epilayers will be optimized with respect to the III/V ratio, N2 flow and RF power. Efforts will be made to achieve relaxed AlN buffer, coherently grown strained GaN and relaxed ultra-thin AlN barrier on top. The effect of barrier thickness on the 2DEG density and carrier mobility will be studied to achieve the highest 2DEG density while maintaining high mobility, resulting in higher device current densities and transconductances.

In addition, the optimised layer structure will potentially exhibit lower contact resistance and gate leakage, which are expected to drive these heterostructures to be attractive for very high-frequency RF applications at lower operating voltages than conventional AlGaN/GaN HEMTs. The surface, electrical, structural and optical properties of the grown layers will characterized using advanced tools such as AFM, Hall, CV, HR-XRD, Raman and HR-TEM and the results will be correlated to growth parameters.

Supervisor: Assoc Prof Radhakrishnan K. (EEE)
Co-Supervisor: Dr Dharmarasu Nethaji (TL@NTU)

6. Investigation of The Bendable Behaviour of Diamond for Thermal Management Applications

Diamond, with extremely high in thermal conductivity (TC) of beyond 2000 w/m k, it is the highest TC material and deemed to be the ultimate solution for thermal management challenge. However, it is also due to its extreme hardness and therefore, challenging to provide direct conformal contact with the heat source and not effective for heat extraction. This limitation might soon be able to overcome as recently, there is an experimental discovery that monocrystalline and polycrystalline diamond nanoneedles can be deformed reversibly to local elastic tensile strains at room temperature. By exploiting such bendable phenomenon of diamond, perfect thermal contact may soon be achievable, a game changer to the electronic world.

Herein, the objective is to investigate this new type of advance diamond that is compressible to address the need as thermal contact, without the need to sacrifice much of the TC of diamond. Various synthesis methods will be explored and examined with our state-of-the-art material characterization systems. Importantly, the thermal behavior as a function to the straining of these new diamond will be investigated. Due to the complexity and the scope of the investigation, there will also be collaboration with international diamond experts for advice, advance characterization, and validation of the materials.

Supervisor: Assoc Prof Edwin Teo (EEE/MSE)
Co-Supervisor: Dr Tsang Siu Hon (TL@NTU)

7. Advanced High Performance and Functional Fibre Materials

High performance fibres especially those with specific functionality have found a broad range of applications beyond textile and fashion. These applications include those in energy, electronics, biomedicine, environment, defence and aerospace.

In this project, the candidate will be working with an interdisciplinary research team to explore the design, fabrication and applications of new generation of fibre materials based on advanced polymers, carbon nanomaterials, ceramics and/or composites. The objectives of this PhD thesis are (i) to develop fibre precursor materials with desirable thermal-mechanical properties, fibre spinnability, and other functional properties such as electric and thermal conductivity, (ii) to establish the fabrication feasibility of micro- or nano-fibre spinning with advanced various spinning techniques, e.g., wet-spinning, dry-spinning and electrospinning, and (iii) to explore these new fibre materials in engineering applications. The cross-disciplinary knowledge gained in the study will help in-depth understanding of the critical relationships among chemical structures, micro-/nano-architecture, fabrication processes and functional properties. The project may also include an element of sustainability and green fabrication. New knowledge, technology and capabilities will be developed through innovation towards synthesis, fabrication and application of next-generation fibre materials.

This project plans to build upon the on-going collaboration initiatives with RICE University, Hebrew University of Jerusalem, and/or University of Manchester. Candidates having passion in innovative research and holding a good degree in a relevant science and/or engineering discipline are encouraged to apply.

Supervisor: Prof Hu Xiao (MSE)
Co-Supervisor: Assoc Prof Edwin Teo (TL@NTU)

8. Development of Advanced Multifunctional Materials

Advanced systems are envisioned to be lean, efficient and resilient against changing environmental conditions, capable of delivering their goals under stresses that would usually overwhelm conventional setups. A key component of such advanced systems is multifunctional materials. By having a single material perform multiple roles, not only can heavy, complex and fragile multi-material systems be avoided, but redundancies can be built in so that one material can take over the role of another seamlessly should any one of them fail during operation.

The aim of this project, therefore, is to develop advanced materials that can provide functions including, but not limited to, lightweight structural support, high thermal conductivity, sensing, shape-morphing, filtration and/ or energy storage. To achieve this, a combination of additive manufacturing and nanotechnology advances will be employed to realize novel materials such as architected nanodiamond/carbon nanotube/graphene microlattices. The project will leverage on high-level custom design, synthesis and characterization techniques developed in our labs over the past years to break new grounds in fundamental and applied investigations in multifunctional materials.

Supervisor: Asst Prof Lai Changquan (MAE)
Co-Supervisor: Dr Seetoh Peiyuan Ian (TL@NTU)

9. Molten-core Method for High-Power Fiber Lasers

Optical fibers have transformed our lives. They are the primary physical channel for exchanging information in global communication networks, supporting cutting-edge speed and bandwidth. They are widely used in optical sensing of mechanical stress and strains for structural health monitoring in buildings and other infrastructures. Another sector that has seen a tremendous growth by adopting optical fibers is the high-power laser industry. The fiber formfactor is ideal for maximizing the pump absorption and thermal cooling that are critical for increasing the lasing power. Moreover, the fiber platform guides the light along its mechanically flexible path and removes the need for beam alignment, offering exceptional operational stability and beam quality. Hence fiber lasers have been the main driver in the high-power laser domain for industrial applications in the last decades.

The active medium in a fiber laser is an optical fiber doped with rare-earth elements such as erbium, ytterbium, and thulium. A common way to fabricate the active preform is to use a technique called modified chemical vapor deposition, or MCVD, to dope the active elements in the host glass. However, not all dopants can be easily incorporated with the vapor deposition method, which restricts the glass composition that can be synthesized using MCVD. This is a major drawback as the fiber lasing performance can be enhanced significantly by modifying the glass composition.

An alternative approach to overcome this limitation is the so-called molten core method, where fiber is directly fabricated by placing starting powder in a silica tube. The high-temperature drawing facilitates the chemical reaction to form the target material composition in the fiber. Indeed, multi-component fibers forged in this way have shown promising results, but there are also many prevailing issues that must be addressed before the technology can be adopted for active fiber fabrication for high-power lasers. The most urgent issues currently are the high background loss, high refractive index contrast, and low laser efficiency. In the Thesis, the candidate will address these challenges to firmly establish the molten core method for active fiber fabrication, which has the potential to revolutionize the high-power fiber laser technology.

Supervisor: Asst Prof Chang Wonkeun (EEE)
Co-Supervisor: Dr Charu Goel (TL@NTU)

10. High power and high brightness on-chip grating stabilized semiconductor diode lasers

Semiconductor based high power laser diodes (HPLDs) have been widely used in many application fields. These semiconductor HPLD modules are compact in size, reliable, cost effective, as well as efficient in optical-electrical conversion. Recently, much attention has been paid to the brightness of the HPLDs. High-brightness, high-power laser diode could be used for optical pumping of solid state lasers and fiber amplifiers, material processing, free space communications, and medical treatment with improved performance. In addition, wavelength stabilization is another critical aspect for high power laser diode.

This project aims to develop high power, high brightness, and low cost on-chip grating laser diode. With these aspects, i.e., simultaneous high beam quality, high power and wavelength stabilization, the HPLD performance can be improved. The bulky coupling and wavelength stabilizing optics can be removed. Therefore, high power, high performance, low weight, and small size HPLDs could be achieved.

Tapered waveguide and laterally inhomogeneous waveguides laser diode is a promising concept for the combinations of high-power and nearly diffraction-limited beam quality in order to obtain high brightness. In addition, on-chip grating is beneficial to the wavelength stabilization. Therefore, in this project, the major scope of work will cover following.

(1) Large optical cavity (LOC) quantum well laser structure will be designed for high power and low divergence angle;

(2) to design tapered waveguide structure (with LOC) for high brightness;

(3) to design internal grating for Distributed feedback (DFB) laser; to design high order grating on the semiconductor for wavelength stabilization to avoid the re-growth;

(4) Optimization of the fabrication of waveguide, flare angle, laterally inhomogeneous waveguides.

(5) Optimize and fabrication of the grating structure.

In summary, this PhD topic is focused on the simultaneous realization of high power, high brightness, wavelength stabilization for high power semiconductor diode lasers, which is important for their applications. The above proposed research field will be well fitted for NTU's dynamic world level cutting-edge program. In addition, the proposed topic on high power laser diode also has great significance in both commercial and defence applications. For example, in commercial application, to name a few, high power lasers can be used for Optical pumping, Biomedical and Analytics Instrumentation, Materials Processing, Optical communication, Lidar, Printing, Imaging, and many others. For defence application, high power laser diodes can be used as Laser weapon, Night Vision, Laser Designation, Range Finding, Target Designation, Illuminators, Solid State & High Energy Laser Pump Sources, and so on. Obviously, improved high power laser performance to be achieved in this exciting PhD project can better enhance their use in above mentioned application fields.

Supervisor: Assoc Prof Wang Hong (EEE)
Co-Supervisor: Dr Liu Chongyang (TL@NTU)

11. 3D Printing of Conductive Elastomers for Elastomers for Flexible Electronics

The concept of flexible electronics has broadened the horizons for electronic technology, allowing it to take on unique form factors for novel and advanced applications such as soft robots and wearable electronics which could be highly desirable for the defence industry. The implementation flexible electronics in robotics could expand the limits in unmanned operations, such as improving manoeuvrability in confined spaces and safer interactions with human beings. The incorporation of wearable electronics in exercises could enable the health monitoring of soldiers which could prevent injuries and improve training efficiency.

Hence, driven by the rising interest in flexible electronics, electrically conductive elastomers have been a topic of intense research interest. The flexible and resilient nature of elastomers allows for continuous deformation, making them desirable for use in wearable electronics and as sensors. To achieve desirable sensory feedbacks, it is preferable to implement conductive elastomer with heterogenous electric conductivity. 3D printing, especially multi-material 3D printing, unlocks great possibilities for the design and fabrication of conductive elastomers with programmable conductivity and 3D geometries.

Among various 3D printing techniques, powder-based Multi jet fusion (MJF) printing can rapidly fabricate complex parts in a support-free manner. With the multi-ink printing system, MJF enables localised introduction of various functional conductive fillers (e.g., carbon nanotubes, graphene, and liquid metals) into elastomeric matrix through locally jetting specially formulated inks.

Therefore, MJF shows strong potential in achieving rapid fabrication of conductive elastomers with tailorable conductivity for electronic applications. However, the MJF printing of conductive elastomers is still in its infancy, and the conductive ink materials applicable for MJF are limited and remain a significant challenge. Hence, this project aims to develop MJF printing of flexible conductive elastomers for 3D conformal flexible electronics through a systematic framework, including material development, structural design, and process optimization. The development of such processes will establish a rapid manufacturing technique for fully customisable flexible electronics with strong prospects for a multitude of applications.

Supervisor: Prof Zhou Kun (MAE)
Co-Supervisor: Assoc Prof Edwin Teo (TL@NTU)

12. Investigation on the Hardware Security of Advanced Microchips

Nowadays, electronic devices are becoming our sixth sense and the technology behind many of the cutting-edge digital devices depends on the development of advanced semiconductor chips. Thus, the security of the data stored in microchips is one of the major concerns. In the past decade, various non-invasive and invasive techniques have been reported to retrieve secret data concealed in secure integrated circuits (ICs). Using laser beam is considered a very efficient technique to inject faults into ICs with high accuracy. On the other hand, some countermeasure techniques and designs, such as current sensors monitoring and use of fully depleted silicon on insulator for the chip fabrication, have been developed to make the storage of the data more secure for advanced ICs. However, these security designs were developed against existing attacking techniques. It is still unknown if these designs are safe under novel attacking methods.

The main objective of this project is to research on the hardware security of advanced microchips. The security of the devices will be evaluated through existing and newly developed semi-invasive and/or invasive attacks to simulate hackers in retrieving the secret data in advanced microchips, with the aid of advanced microelectronics failure analysis techniques. The attacking techniques investigated and results obtained in this study will help the chip designers and manufacturers to strengthen and enhance the security of existing and future electronic devices to prevent such future attacks.

Supervisor: Prof Gan Chee Lip (MSE)
Co-Supervisor: Dr Liu Qing (TL@NTU)

13. 3D Printing of Boron Nitride Architectures with Tailored Properties for thermal Management Solutions

Efficient extraction and regulation of heat has become a prevalent bottleneck for high-performance miniaturized electronics and optoelectronics systems. Boron nitride (BN), which is a distinct class of 2D material, is an ideal candidate for such applications as it is uniquely electrically insulating yet highly thermally conducting (> 2000 W m-1K-1 in theory) and its ability to withstand extremely high temperatures. However, traditional manufacturing is costly and time-consuming and lacks the capability to fabricate intricate structures with complex geometries and customizable designs.

Here, we use 3D printing to create structurally engineered architectures of BN with tailored thermal properties to provide customized thermal management solutions for various electronic systems. A scalable synthesis approach will be investigated to fabricate large quantities of BN nanosheets which will be the basis for ink formulation. Tuneable thermal properties ranging from highly conducting to insulating can be achieved through variations in ink designs as well as microstructural engineering. Utilizing direct ink writing (DIW), customizable 3D geometries of BN structures can be patterned and deposited on demand with high precision and on uneven surfaces catering to different electronic devices and applications. Validation of our developed materials and thermal performances will be conducted using our in-house state-of-the-art material characterization systems and externally through collaborations with our industry counterparts.

Supervisor: Asst Prof Roland Tay (EEE)
Co-Supervisor: Dr Tsang Siu Hon (TL@NTU)

14. Ultrafast joining of advanced ceramics for enhanced mechanical properties

Due to the challenges in fabricating large ceramic sizes, ceramics often need to be joined together directly or with metals for practical applications. Traditional joining processes such as brazing and diffusion bonding requires long-term exposure of entire assemblies to high temperature in a chamber furnace, and thus it is an energy/time-consuming process. The long-time exposure of the ceramics at high temperatures could also degrade their mechanical properties. Therefore, selective, ultrafast joining techniques with the assistance of electric field or microwave are attractive to make the process more efficient. As an emerging, novel joining process, there is still a lack of a good understanding on these joining techniques for advanced ceramics, especially 3D printed ceramics with complex architected structures.

This project aims to develop an ultrafast bonding technique using electric field and/or microwave to promote more localized heating and material diffusion processes so as to realize a strong joint at the ceramic interfaces. The joining interfaces with unconventional topology will be designed and 3D printed to further enhance the bonding strength. The effects of the filler material, energy input, and interface structures on the mechanical and thermal properties of the joined ceramics will be systematically studied. The application of the optimized joining technique to large size ceramic and ceramics with complex architected structure will also be explored.

Supervisor: Prof Gan Chee Lip (MSE)
Co-Supervisor: Dr Du Zehui (TL@NTU)