Nanyang-DSO Graduate Programme (NDGP) 2025

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 AlN which could provide more efficient heat dissipation thus further enhance the performance and reliability of GaN HEMTs for next generation Power Amplifiers.

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 gate (e.g: 20 to 40 nm) 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 required.

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 research topic is to explore different approaches to realize mm-wave operating devices by the optimization of device architecture design (e.g. Fin-HEMTs), device simulation, device fabrication and its electrical (DC, Pulsed I-V and RF) characterization. The measured device data can also be correlated with the in-coming HEMT epi-characteristics as well as device processing parameters.

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. Multi-Channel GaN HEMT or GaN-on-Diamond), deep scaling to increase the operating frequency, device passivation to suppress the current dispersion, device fabrication and its electrical (IV, Pulsed I-V, CV and RF) characterization. The measured device data can also be correlated with the in-coming HEMT epi-characteristics as well as device processing parameters.

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

4. Development of GaN based HEMTs on diamond using CVD deposition for improved areal power density

GaN HEMT based devices are capable of delivering power densities of more than 40 W/mm. However, self-heating is a serious issue for GaN HEMTs, since it degrades device performance and causes catastrophic device failure at high power densities. Currently, GaN HEMTs on SiC are the standard devices for GaN based RF applications. Even though the SiC substrate has a relatively high thermal conductivity (390 W/m.K), the thermal resistance of GaN HEMT on SiC remains a limiting issue for developing RF devices with high output power densities. Diamond has the highest thermal conductivity, up to 2000 W/m.K, which is over four times that of SiC. Simulations and experiments show that GaN HEMT on diamond can operate at 40¬ to 50% lower temperature than GaN HEMT on SiC devices and are capable of delivering more than three times the areal power density than that of state-¬of¬-the-¬art GaN HEMT on SiC devices for RF power applications. In this study, GaN HEMT on diamond will be established by direct deposition of diamond on GaN HEMT heterostructure using chemical vapor deposition (CVD). The challenges with this approach are CVD growth temperature induced stress due to thermal expansion coefficient mismatch and the thermal conductivity limitation of the CVD diamond layer which is in the range of 1500 W/m.K.

In addition, the bow of the freestanding-GaN on diamond (100 μm thick) is a challenge for device processing. In this study, carrier wafer bonding processes will be established for achieving lower bow before and after CVD diamond deposition using Si and diamond carrier wafers, respectively. CVD diamond growth and the structural and thermal characteristics of diamond will be investigated using tools such as MPCVD, AFM, HR-XRD, and thermal conductivity measurement (3□) method. Finally, thermal boundary resistance (TBR) between GaN and diamond will be investigated using techniques such as time-domain thermo-reflectance (TDTR) and the methods will be established to reduce TBR between GaN and diamond. The optimised GaN on diamond with lower TBR will be used to demonstrate GaN HEMT on diamond device characteristics.

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

5. 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)

6. 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)

7. Advanced Design and Manufacturing of Evolutionary Electromechemical (EMC) Systems

To deliver mission-critical capabilities under a wide variety of environmental conditions, advanced systems need to be lean, efficient and adaptable, like a human body, with each module capable of carrying out multiple tasks simultaneously. These tasks should overlap to confer built-in redundancies that will allow one module to take over another seamlessly, should any of them fail during the operation. Moreover, the system should be able to rejuvenate upon failure, evolve, then counter the original environmental setback. Such demanding performance require an unprecedented, multidisciplinary integration of the chemical, electrical and mechanical aspects of unique material systems.

The aim of the project is, therefore, to design and develop material systems that can provide active electromechanical sensing, electrochemical energy storage and chemomechanical responses to environmental stimuli, in addition to passive thermal, electrical and structural support. To achieve this, the project will make use of advanced design and simulation methods driven by first-principles calculations and custom Machine Learning/ Artificial Intelligence (ML/AI) models, as well as high-level nano- and additive manufacturing techniques developed within our labs over the past decade to derive new scientific and engineering insights into these evolutionary material systems.

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

8. Mode-preserving fiberized laser beam delivery at kilowatt levels

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 strain for structural health monitoring in buildings and other infrastructures. Another sector that has seen tremendous growth by adopting optical fibers is the high-power laser industry. The fiber form factor is ideal for thermal cooling that is 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 high-power laser domain in the last decades.

One of the key features that makes the fiber laser so versatile is the ability to deliver the output beam via fiber, transporting the laser beam directly on to the target. However, at high beam powers, the delivery fiber may exhibit strong nonlinear effects, such as the thermal mode instabilities, which can severely impact the beam quality. Many approaches have been proposed and tested to reduce the nonlinear effects, but most entail introducing other undesired effects, such as the onset of multiple spatial modes that deteriorate the focusing power of the laser beam.

A promising solution to this challenge is hollow-core optical fibers, which guide light in their central hollow region, assisted by microstructured cladding surrounding the hollow core. They have been under active development in the past decade, with the latest breakthroughs demonstrating lower transmission losses than telecommunication-grade fibers. By guiding the laser beam in the hollow region, we can bypass the nonlinear effects induced in the waveguide material, enabling distortion-free high-power laser beam delivery.

In the Thesis, the candidate will develop a kilowatt-level laser beam delivery system using hollow-core fibers, which has the potential to disrupt the high-power fiber laser industry. This will involve designing, fabricating, and characterizing low-loss hollow-core fibers that are mode-matched to the laser output fiber. The design will require numerical simulations based on finite-element modeling. Fabrication will be carried out at our local fiber fabrication facility. Furthermore, a strategy to reliably and repeatably integrate the delivery fiber into the high-power laser through thermally resistive, mode-matched fusion splicing will be developed.

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

9. 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)

10. Hardware Security Analysis of Advanced Microchips through Failure Analysis Techniques

Nowadays, electronic devices have become an integral part of daily life, storing sensitive data such as personal privacy and banking information. Therefore, the security of data stored within microchips is a critical concern. Over the past decade, a range of non-invasive and invasive techniques has been reported that attempt to retrieve secret data from secure integrated circuits (ICs). Among these, the use of laser beams is considered one of effective approaches for injecting faults into ICs with high precision or directly probing data.

In response, several protective techniques and designs have been developed, such as current sensor monitoring and the use of fully depleted silicon-on-insulator technology in chip fabrication. These measures are designed to fortify advanced ICs against methods like laser probing, significantly enhancing the security of data storage. However, while these security measures are effective against known attack techniques, it remains uncertain whether they can withstand emerging attack methods, especially those combine traditional approaches with artificial intelligence.

The main objective of this project is to strengthen the hardware security of advanced microchips. By employing both existing and newly developed semi-invasive and/or invasive attacks, as well as advanced microelectronics failure analysis techniques (such as electron probing and imaging) and intelligent image processing, we aim to simulate potential threats posed by hackers attempting to access confidential data. The insights gained from studying these attack techniques will aid chip designers and manufacturers in enhancing the protective capabilities of current and future electronic devices, ensuring a higher level of security against evolving threats.

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

11. 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)

12. Novel synthesis and applications of ceramic composite nanofibers

One dimensional ceramic nanofibers possess a good scope for applications in thermal management, aerospace, EMI shielding, energy harvesting and storage, etc. However, the chemical, mechanical and thermal stability of these nanofibers should be improved and systematically investigated for their deployment in various applications. Therefore, the objective of this study is to explore novel methods for the synthesis of ceramic nanofibers with improved electrical, thermal, and mechanical properties.

Among various ceramic nanofibers, significant efforts have been devoted to the synthesis of the boron nitride nanofibers (BNNF) owing to its excellent thermal and dielectric properties. Typical BNNF synthesis methods such as electrospinning may yield BNNF with a random distribution of boron nitride orientation within the fiber, which may influence the stability of the fiber. Herein, novel spinning methods for the synthesis and approaches for characterization of BNNF will be investigated. Polymeric, metallic, and carbonaceous nanofillers, will be incorporated with the BNNF precursor materials, to synthesize high performance multi-functional boron nitride composite nanofibers for potential deployment in harsh environments. The electrical, mechanical, and thermal properties of the synthesized boron nitride composite nanofibers will be benchmarked against commercial ceramic nanofibers. Subsequently, the knowledge gained will be utilized to synthesize other novel composite nanofibers of interest.

Supervisor: Asst Prof Roland Tay (EEE)
Co-Supervisor: Assoc Prof Edwin Teo (TL@NTU)

13. 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)