Nanyang-DSO Graduate Programme (NDGP) 2023

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. Mechanical Metamaterials: Design, Additive Manufacturing and Multifunctional Applications

Due to their specific architected microstructures, mechanical metamaterials exhibit exceptional properties and functionalities that are unattainable by any conventional engineering materials. Additive manufacturing techniques, especially those in microscale domain, provide exciting emerging possibilities to fabricate complex metamaterial structures for broad range of applications including those in energy, electronics, biomedicine, 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 mechanical metamaterials based on advanced polymers, ceramics and/or composites. The objectives of this PhD thesis are (i) to develop metamaterials with desirable mechanical properties, low density, thermal stability, and other functional properties, (ii) to establish the fabrication feasibility of micro- or nano-architectures with advanced additive manufacturing technologies, and (iii) to explore these new metamaterials in engineering applications. The cross-disciplinary knowledge gained in the study will help in-depth understanding of the critical relationships among chemical structures, geometrical micro-architecture, fabrication processes and functional properties. Intellectual properties will be developed through innovation towards practical applications of next-generation metamaterials. This project plans to build upon the on-going collaborative programme programme with MIT, Hebrew University of Jerusalem and local scientists in a related field. Candidates having passion in innovative research and degree in a 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: - (TL@NTU)

9. Novel multifunctional materials for electronics

The rise of additive manufacturing has allowed access to complicated and intricate material designs, which cannot be achieved with traditional fabrication techniques. With greater access to such material designs, innovations in material architectures allows for the fabrication of advanced materials with enhanced properties. Such technology has been utilised in fields such as printable electronics. Despite the recent advances in additive manufacturing techniques, there are still multiple ongoing challenges to be addressed. Significant challenges include the search for compatible materials with enhanced functionalities, and high resolution of printed device architectures.

This project aims to develop the next generation of printable electronics, based on new materials (polymers, ceramics, liquid crystals, etc.) with multiple functionalities (healing, conductive switch transitions, etc.), expanding the scope of materials compatible for printing. Novel substrates with enhanced functionalities in processing and performance will also be explored. By combining new material chemistries and novel printing techniques, devices with enhanced properties can be utilised for unprecedented applications.

Supervisor: Assoc Prof Nripan Mathews (MSE)
Co-Supervisor: Dr Du Zehui (TL@NTU)

10. 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: - (TL@NTU)