THE PROMISE OF TOMORROW

CREST

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How Gallium Nitride Technology Lights A Path for Malaysia

by CREST

"At the giddying pace of technological change today, the stakes are high for anyone who wants a place at the forefront."

INTRODUCTION

The Promise of Tomorrow

Imagine being a fly on the wall during an economic forum on Malaysia's future prospects. The details might vary, but the storyline would likely go like this: the country of 30 million has punched above its weight since coming into being in 1963, its fortunes resting largely on primary commodities and the trade of intermediate goods for the global market. But it now needs to dig its heels deeper and identify new areas of growth, centred on innovation and buoyed by a capable workforce.

In Light We Find Hope

If policy prescriptions can provide the broad brushstrokes of what Malaysia needs, the stories in “Promising Tomorrow” tell us the textured details from up close. The technology in question is gallium nitride (GaN), in the field of optoelectronics. The individuals, their purposeful camaraderie and the events that led to action are given the spotlight. The compilation is timely, as the sun sets on the first five years of a collaborative, multi-agency and international programme to develop GaN technology in a quest to enhance Malaysia’s future.

In Chapter One, we learn about the background to the GaN programme and the reasons behind its launch. Chapter Two focuses on the progress in research, specifically in the collaboration within a network of university-based labs in Malaysia, known as The Mirror Labs, and the Solid State Lighting and Energy Electronics Centre (SSLEEC) at University of California Santa Barbara (UCSB), the United States. In Chapter Three, stories of talent development come to the fore. In closing, Chapter Four looks back in reflection, and lays out what’s next for the programme.

A Matter of Technology

The GaN programme resides within materials science. An interdisciplinary field focused on the properties of matter and their application in many areas of life, materials science draws from physics, chemistry and multiple branches of engineering. Since time immemorial, materials have been a part of human history, going back to when the first humans lived alongside and, yes, occasionally went to war with one another. The natural or manufactured materials that we mould, melt, smelt, and manipulate underlie the reaches of technology, which are in turn propelled by the forces of human imagination.

But technology's power to captivate lies in its impermanence. What was cutting edge in one era becomes a museum relic in another. For this very reason, we might giggle at the quaint sight of a VCR player in a living room in 2022, or recall nostalgically the click-clack of abacus beads as we tap away at a scientific calculator.

At the giddying pace of technological change today, the stakes are high for anyone who wants a place at the forefront. It is no coincidence that spending in research and development (R&D) has become a mark of a country's resolve to become a technology powerhouse.

A Place for Malaysia

Malaysia might not be in the league of technology powerhouses, but size is no barrier to become an important player in the field. Absent the gargantuan funds to pour into technology development compared to other countries, the secret to success lies in foresight, focus and collaboration.

Earnest enthusiasm can be a great propeller too, and describes the vibe of our lead character in "Promising Tomorrow," Collaborative Research in Engineering, Science and Technology Center, or CREST for short. Established in 2011, CREST's expressed role is to work together with the government, industry and academia and smoothen their cooperation in charting a future path for Malaysia's electric and electronic (E&E) industry.

Ready to be a friend to all and beholden to none, CREST identifies focus areas in consultation with industry players, whose place in the proverbial trenches position them well to offer commercial insight. The government provides financial support and guidance on aligning CREST's goals with national policy objectives. Members of academia meanwhile, are roped in as counterparts to industry in research. By working together, they move faster and in step with the urgency of finding new pathways for Malaysia's technological growth. Investing time, effort and heart into a country can play out in many ways, and the stories here show the micro, more human sides to a national project in science and technology.

Of Camaraderie and Collaboration

The stories in "Promising Tomorrow" are also about building on existing strengths, which are themselves pay-offs from wise decisions from the past. Building upon policies adopted in the 1970's, today Malaysia is known as a global production site for light emitting diodes (LEDs), tiny devices that conduct electricity to produce light. Lights made with LEDs last longer than traditional light bulbs, use energy more efficiently and shine brighter. But bit by bit, the passage of time has dulled Malaysia's LED lustre. Bigger players have come into the picture, for example China which has enough fabrication facilities to supply the entire world with LEDs.

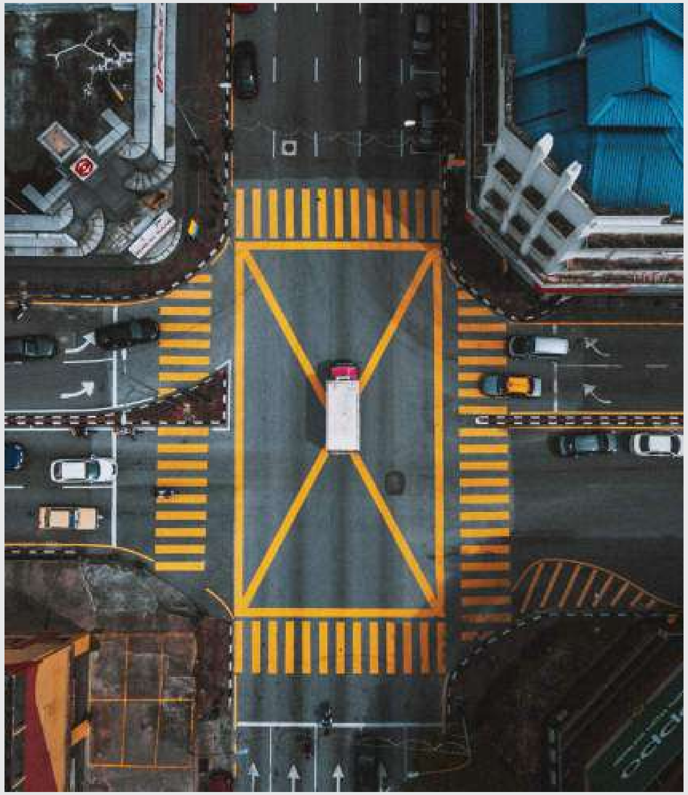
The Power of Collaboration

This brings us to gallium nitride, a compound made up of gallium and nitrogen. Because gallium has three outer electrons which bond with nitrogen's five and form a substance that can both conduct and insulate electricity and heat, GaN is what you call a III-V semiconductor. It's a powerful material system capable of forming the bedrock of industries which the world doesn't even know of yet.

Developing GaN as a component of LEDs and other optoelectronic applications opens the doors to future applications. It deepens the country's skills profile, and can boost its fortunes as an investment destination. The vast possibilities therein, plus the opportunity to leverage the local industry's existing knowledge and know-how in manufacturing make GaN technology very compelling to secure a more promising tomorrow for the country.

Here, you will find stories about where industry insight meets technocratic ambition in an upper middle-income, Southeast Asian country. The nimble operations of a small, impassioned team across cultures and generations will leave you heartened and hopeful.

We hope you enjoy the read.

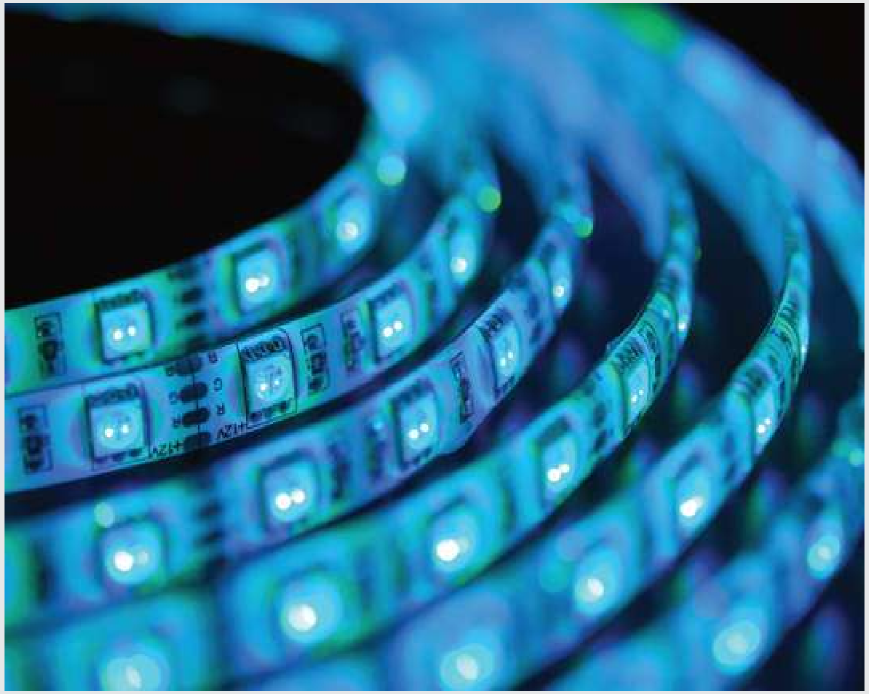


CHAPTER 1

THE **POTENTIAL** **AND PROMISE** OF GALLIUM NITRIDE

What do the European Space Agency, the United States Navy, the governments of Japan and the United Kingdom, and CREST have in common?

Answer: Belief in the potential of gallium nitride (GaN) and active support for GaN-based research to develop mainstay technologies for the future.



Gallium Nitride

Gallium nitride (GaN, pronounced “gan”) is a compound made up of Gallium and Nitrogen. GaN is a type of semiconductor, referring to its ability to partly conduct electricity (hence “semi”). Also known as integrated circuits (ICs) or microchips, semiconductors have been called the brains of modern electronics. They power our smartphones, laptops, televisions, washing machines, and refrigerators, to name a few examples. Their invention paved the way for the modern-day computing and electronics era. They are at the centre of daily life as we know it.

In an atom, band gaps are the space between the outermost electron orbital known as the valence band, and the conduction band. Comparing conductors, semiconductors and insulators, in conductors only a little energy is needed to move electrons through the small or in some cases, non-existent, band gap. In semiconductors, more energy is needed to cross the larger gap, while in insulators which by definition have the widest bandgap, the energy required to cross the gap is too large to be feasible without causing damage.

GaN and its peer materials, such as Gallium Arsenide and Silicon Carbide, are known as wide bandgap semiconductors. This category of semiconductors requires significant amounts of energy to cross the bandgap, but can also be engineered to become efficient transmitters of energy.

It is this interplay between energy and performance that makes GaN a next-generation material. It functions well in higher temperatures, voltages, and currents. It is simply a more powerful material too, and can pack more power per unit than other semiconductors. Higher power density means GaN can complete tasks in a shorter time, a characteristic that makes it the material of choice for fast-charging chargers. Because in the field of design, efficiency is inversely related to size (notice how today’s smartphones are many orders smaller than the clunky mobile phones from the 1990’s), GaN is considered a key ingredient in the small battery packs of the future. Picture a laptop battery the size of a credit card, and it would be almost guaranteed to have GaN as a key component.

In space, GaN's capability in radio frequency output power and its robustness in radiation environments have made it into the European Space Agency's missions that orbit the Earth.

In the sea, GaN is used to build radars that can detect state-of-the-art missiles. The United States Navy invests heavily in GaN with the goal to develop submarine warfare technology that is able to detect fainter objects farther away.

On land, GaN is an enabling technology for efficient power transmission. This is why governments from Japan to the United Kingdom are funding research to develop GaN-based power devices and reduce global carbon emissions in the process.

The tremendous growth in mobile device usage and streaming services around the world increases the use of data, which builds demand for higher speed and greater bandwidth. Here too, GaN's role in high performance radio frequency applications positions it at the frontier of wireless and telecommunications systems.

Beyond these inroads into different areas of life, GaN's potential is most pronounced in the fact that the writing is one the wall for its forerunner in the world of semiconductors – silicon.

Sunset: Silicon

Since the 1960's, silicon has been the material of choice in the semiconductor industry. However, after years of being innovated on, silicon's time is almost up. It is reaching its physical limit to cater to the increasing demands of semiconductor users. In short, it is apparent that silicon will exhaust its potential in power, size, and speed in the not-too-distant future. Some experts say silicon's age of dominance will end in ten years.

All the more reason to focus on successor materials such as GaN.

To be clear, GaN technology is still considered niche. Its application in consumer electronics is relatively small. It's tremendously expensive compared to more mainstream peers. But in science's cycle of discovery, development, and commercialisation, progress takes time. Every hour and around the globe, there are people working on niche technologies, because the niche technologies of today can become the mainstream applications of tomorrow.

Outside of the global arms race or space exploration, Malaysia's interface with GaN technology comes in a more commercial, and civilian, sector. It is a sector embedded in the country's economic history, and tells an illuminating story.

The story is one of looking ahead, of engineering pivots and keeping Malaysia in step with the demands of economic progress.

It is the story of light emitting diodes, commonly known as LEDs.

LEDs: The Gateway to GaN in Malaysia

History can be a great teacher. Looking back in time, the story of GaN technology in Malaysia had its first building blocks laid many years ago. Five decades, to be exact.

The year was 1969. Malaysia was less than ten years old, and a country that had to find its footing and make big decisions that involved saying so long to the old, and embracing the new.

Historically an important port of call to Peninsular Malaysia, Penang had lost its free port status two years before. Policy necessity in the new Federation led to Penang making way for Port Klang, which was closer to the national capital in Kuala Lumpur, as the country's main port.

Truth be told, the Penang economy didn't need just rethinking, but reimagining. The effects of losing free port status would rattle any policymaker. Unemployment in the state was 15%, against the national average of 9%. New solutions were needed fast. On the advice of economic consulting firm Robert R. Nathan & Associates, the Penang state government landed on the idea of establishing a Free Trade Zone (FTZ). Foreign companies could locate certain areas of their production networks in the FTZ in return for tax breaks and other benefits granted by the state government. The focus would be manufacturing, and the main appeal of setting up shop in Penang was that it was a more affordable location for operations, especially compared to the home countries of the companies, mostly in Western Europe and North America.

The state government's trade delegations criss-crossed the globe, selling the story of Penang and its ambitions. Soon enough, the story gained traction. The pioneering eight companies to arrive in Penang were National Instruments, AMD, Intel, Hewlett-Packard, Osram, Bosch, Hitachi, and Clarion.

Getting to Know LEDs: The Hearty Harvest of Vertical Farming

Dr. Sreeraman Subramaniam

LEDs can light up televisions and car headlights, but did you know that they can grow food too?

"At light wavelengths of 400-700 nanometers, plants can grow faster, healthier, and with the ability to produce their own nutrients," explains Dr. Sreeramanan Subramaniam, professor at the Universiti Sains Malaysia (USM) School of Biological Sciences and member of the team behind SeedLab, a spin-off company from the university.

At SeedLab's office in Penang, vertically stacked plots of lettuce and strawberries bloom under rows of LEDs. The multicoloured LEDs create an effect like a groovy 'dance floor' for leafy greens and other plants.

A plant biotechnologist with expertise in plant tissue culture and vertical farming using LED technology, Dr. Sreeramanan clears a few misconceptions:

Credit: Dr. Sreeraman Subramaniam

Are LEDs safe sources of light for planting, compared to the sun?

"Definitely! The plants don't need the entire light spectrum to grow. Light at the wavelengths of the selected LEDs are ideal. Plus, since LEDs are cooler, more affordable and can be left on for as long as is necessary, they are better equipped to grow long daylight plants, the kinds that need 18 hours of daily sunlight."

Dr. Sreeramanan is a big advocate of LED-grown strawberries, for example. "The ones we grow are sweeter, bigger and can be harvested in half the time. They definitely taste better than the ones you get from other places!"

SeedLab has identified opportunities with the growth in indoor farming. The major hurdle for any farmer is getting healthy seedlings. The phase from seed to seedling has a high casualty rate. So, SeedLab can reduce the risks by planting seeds and then selling the seedlings.

Dr. Sreeramanan is enjoying his venture into entrepreneurship, and hopes to see the enterprise grow. "We're pioneers in the Northern region, and definitely cannot work alone. We're looking for genuine industry partners for this transdisciplinary effort."

He also sees wider societal impact.

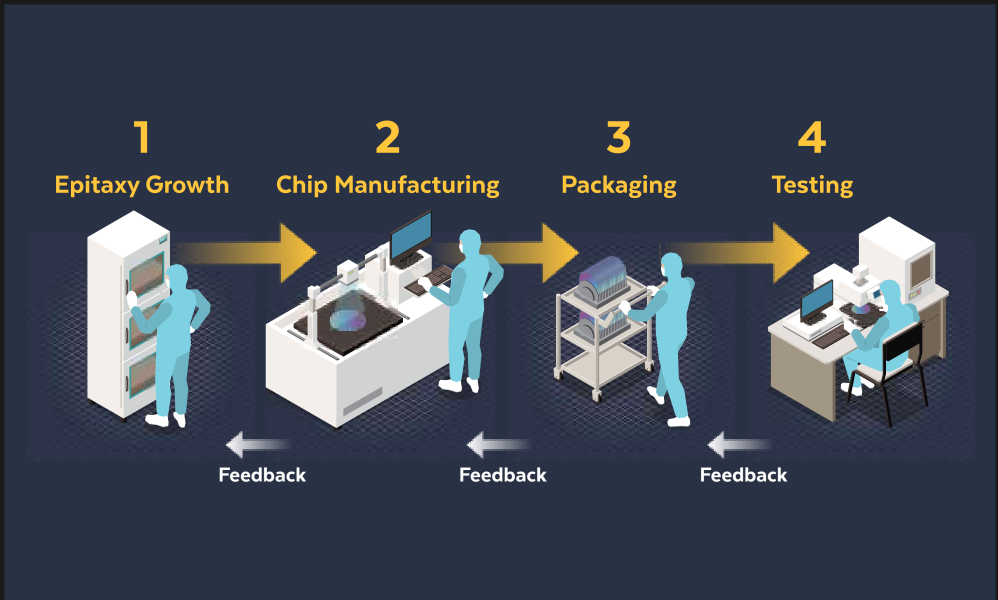
"As an educator, I notice that graduates nowadays are facing issues in unemployment. Maybe for some of them, entrepreneurship is an alternative career option. You could say we're finetuning this idea in agriculture."

Credit: Dr. Sreeraman Subramaniam

Close to half a century later, Penang was synonymous with manufacturing in the electrical and electronics (E&E) industry. A deeper look however, dimmed the blinding lights. The state of local companies in the industry recalled the saying, "What got you to where you are today, won't get you to where you want to be tomorrow."

Lim Hoo Kooi, CREST's GaN Programme Director, describes the situation as such: "In this industry, when companies are just starting out, they will always begin with functions in testing and assembly. But you don't want to keep doing that forever, right? You want to move into more complex, value-adding areas. But that wasn't happening too well among the smaller, local companies."

Cheery and with the knowledge of E&E manufacturing systems like the back of his hand, Hoo Kooi himself could be called a walking manifestation of the decision to give Penang a new look all those years ago. Born and raised in



Making LEDs: The Process

Penang, after graduating in physics he spent a chunk of his career in Intel Penang and looks set to be an industry lifer, both passionate about the subject of bringing Malaysia's E&E industry forward and circumspect about the many challenges that lie in its path.

"This is why we believe so much in the GaN programme. Because we know, learning this technology is the key to moving away from only testing and assembly, and moving into things like epitaxy."

In the LED industry, epitaxy is a technique of growing a thin layer of crystalline material on another crystalline material in a wafer. Made up of wide band gap semiconductors, these layers make up the part that emits light in a LED. Instead of a bulb containing vacuum, the wafer is the light source.

The thing about epitaxy is that learning its ways is tremendously difficult. So difficult that companies which possess the knowledge guard it behind a proverbial fortress. In the cleaved production networks scattered around the globe, employees in sites such as Penang don't receive the epitaxy skills to be able to learn its technique. All that knowledge stays in the home country.

"We found that Penang had close to 200 companies involved in producing LED solutions. But the truth was, most of them didn't have their hands on their own destiny," says Jaffri Ibrahim, the CEO of CREST.

The companies would receive shipments of LEDs that were works in progress, but where all the deeper-skilled functions had already been carried out elsewhere. It was like being part of the production team for the most outstanding cakes ever tasted, only you were the one who received the fully baked cakes from the headquarters and had to work on the icing only. You didn't know the oven temperature, how the ingredients were whipped or folded in, or the grade of butter used. You were a fantastic icing decorator and valued part of the process, but there was always a barrier to you learning the ropes that could potentially make you a spectacular baker in your own right.

And Then There Was (Blue) Light

In 2012, when CREST learnt about this pressing need in the industry, they hardly knew what a solution would look like. They were eager to identify solutions because it would help them find a sense of purpose as a new organisation. But they also tread with caution, keeping their hopes out for game-changing opportunities. From their founding members such as OSRAM[1], they understood the industry picture. From government agencies such as the Malaysian Industrial Development Authority (MIDA), they were assured support but when it came to making a decision, the driver's seat had to be filled by nobody else but CREST themselves.

But when you really desire something, the universe conspires to lead you to it. Or, to put it in a more context-specific rendition: when you're really hoping to meet a collaborator, don't discount the role of industry seminars. In 2013, MIDA organised its annual E&E seminar in Penang, inviting a cross-cutting group of industry players from across the globe.

The keynote speaker was a Japanese gentleman by the name of Shuji Nakamura. A professor at the Solid State Lighting and Energy Electronics Center (SSLEEC) at University California Santa Barbara (UCSB) in the United States, Dr. Nakamura was an icon for his work in LEDs, specifically his accomplishment in finding a method (a "recipe" in industry speak) to create blue LEDs. It was a breakthrough event, as blue LEDs had been elusive compared to red and yellow LEDs, which were invented in the 1960's and 1970's. His success was remarkable because with the blue LED, it became easier to come up with white light applications that were fit for commercial use. From that point onwards, the blue LED was poised to become a foundational, widespread technology.

For the CREST team at the seminar, hearing Dr. Nakamura speak of his work in epitaxy and other functions to build the crystalline layers that emitted blue light triggered a lightbulb moment. Here was a trailblazer in the field who was actively carrying out research on applications with tremendous promise for society. And he was speaking to a crowd in a country which desperately needed a propulsive push to revive its fortunes in the LED industry.

After conferring among themselves, the CREST and MIDA team approached Dr. Nakamura and gauged his interest in some sort of collaboration. Something that shared know-how from UCSB with local researchers, and helped create a local talent pool. Malaysia had plenty to offer in such a partnership, because its longstanding experience in manufacturing made local companies familiar with different parts of the production line, useful information for university researchers. With some brainstorming, the potential partners could agree on something, no doubt.

At first, Dr. Nakamura suggested a visiting researcher programme at UCSB for Malaysian researchers. Seeking an arrangement that left a longer lasting impact on the Malaysian landscape, CREST and partners suggested an expanded proposal. Their aim was to build the appropriate technology infrastructure to allow local scientists to continue "pushing the envelope" and work together with industry to generate intellectual property (IP) once they returned from California. There was a need for a more embedded space to nurture talent. This eventually led to the Mirror Labs, the topic of our story in Chapter Two. Right smack in the middle of negotiations, Dr. Nakamura was announced the joint winner of the 2014 Nobel Prize in Physics, for his achievement in creating the blue LED. All of a sudden, the stakes increased and competition to work with such an illustrious mind became stiffer.

But CREST and co had early mover advantage, and stayed the course in crafting a desired collaboration.

The rest, as they say, is history.

[1] Now known as ams OSRAM following a merger in 2021

CHAPTER 2

RESEARCH: OF **MIRRORS**, **DIMENSIONS** AND **DIAGONALS**

A place called the Low Dimensional Materials Research Centre isn't one where you'd expect to find an air fryer. Yet, there it sat in the meeting room: a round, matte black cooking appliance in a building dedicated to applied physics research, complete with tinted lab windows, controlled access, and strict safety protocol.

"That's for my students, to make meals when they spend the night here," goes the amused explanation by Dr. Ahmad Shuhaimi Abu Bakar, associate professor of physics at the University of Malaya and head of the Centre, abbreviated as LDMRC.

An item that blurs the boundaries between home and workplace is, in fact, a fitting symbol of the rhythm of work at LDMRC.

Time is precious when one is growing LED wafers. Taking between five to eight hours each time, the researchers have to monitor and manage a reactor as it "grows" the ultra-thin layers. Known as a Metal Organic Chemical Vapour Deposition (MOCVD) reactor, it is also the name of its deposition technique or the process by which each layer is placed on the wafer in the desired order. Sometimes researchers complete two to three growing cycles in a day, which makes spending the night at the lab par for the course. In the process, they are acquiring highly specialised skills in epitaxial growth, a method to grow layers of crystals on the wafer surface. Each wafer is then cut and packaged into chips.

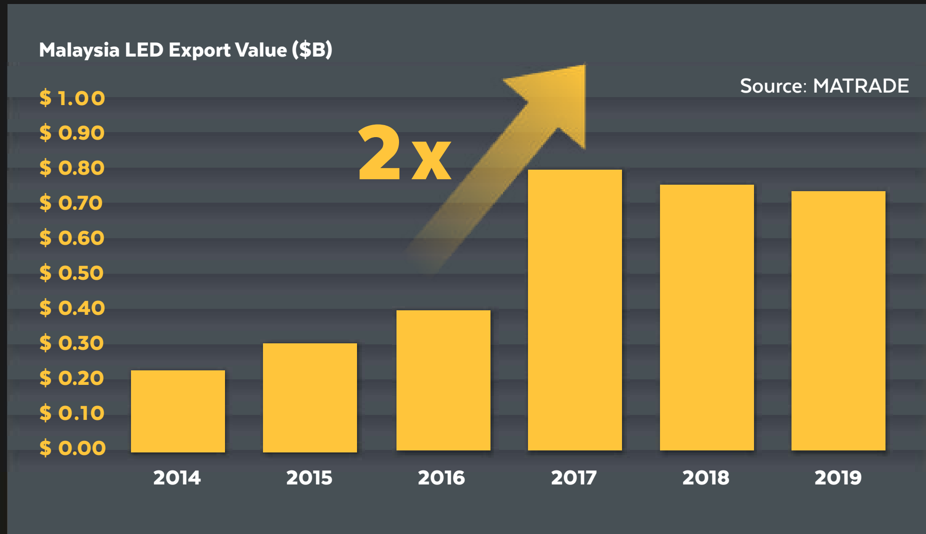
Suspense is stitched into the experience. After hours of controlling the gas flow, the mix of chemicals and the set-up of the reactor, there are defects to watch out for. What's an example of something that could go wrong?

"If the buffer layer that keeps the electrons in the quantum wells isn't formed properly, you might get phonons instead of photons," shares Dr. Shuhaimi. The result? Vibration, instead of light. Not an ideal outcome for the objective at hand.

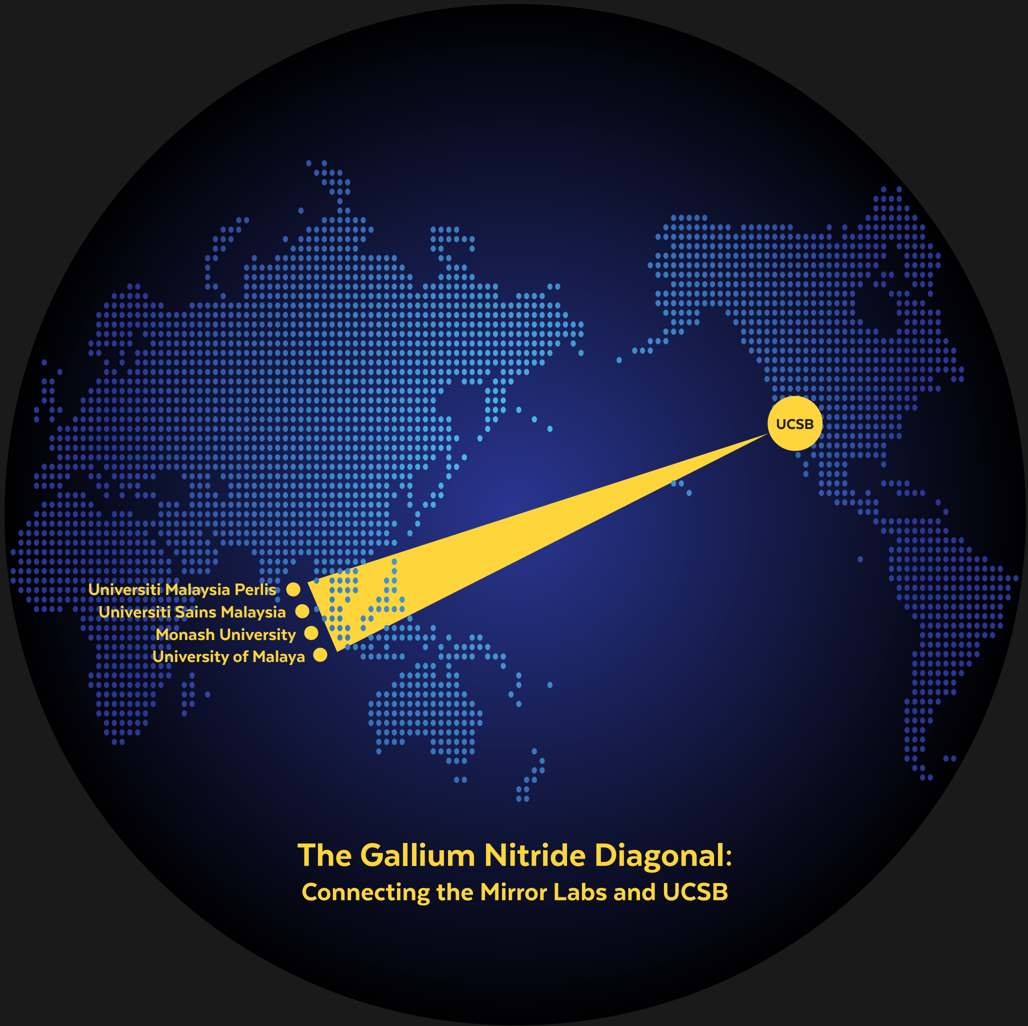
Dr. Shuhaimi runs a tight ship at LDMRC. An expert in semiconductors, he supervises his team of 15 students and dives into his first love: research. One of his principal research areas is producing LED wafers of different colours, with gallium nitride as a substrate. At the moment, using GaN technology may be prohibitive in terms of cost, but Dr. Shuhaimi is optimistic that change is just a matter of time.

"A two-inch GaN wafer costs around RM 2000, maybe even RM 1000 depending on the vendor. Many years ago, it would cost you as much as a small car. I predict that in ten years, this will drop to RM 50 – RM 150, making commercialisation more viable.

But for now we're focusing on developing the technology, which gives us the know-how and the intellectual property. Then by the time GaN wafers become cheaper, we can attempt commercialisation."



- Global LED marketing is growing
- Overall Malaysia LED Export value is growing for the last 4 years
- A big leap (2x) from 2016 to 2017 mainly due to the value add of the fab and epitaxy facility in Kulim, Kedah. Epitaxy makes a significant contribution to export values.



The Gallium Nitride Diagonal:
Connecting the Mirror Labs and UCSB

LDMRC is a member of the GaN Mirror Labs programme. A major research undertaking, the Labs replicate the labs at UCSB's Solid State Lighting and Energy Electronics Centre (SSLEEC). By flattening the learning curve for the Malaysian GaN fraternity, the programme allows them to deepen their research capabilities and ultimately, leave a meaningful impact on the country's technology landscape.

Of Chance and Opportunity

If life is about connecting the dots in a person's journey, then the Mirror Labs are a nice, shiny dot that extends to Dr. Shuhaimi's recent past and nudges it closer to his envisioned future. Years ago, he made a major life decision: after nine years in Japan where he studied up to a doctorate and launched his career, he wanted to return to Malaysia.

The reasons this was a questionable idea were many, and Dr. Shuhaimi didn't need to be told. Could a local academic salary match what one earns abroad? In developed countries, billions in research funds are disbursed year by year. How could Malaysia possibly keep up? What if his career plans didn't pan out?

"I told myself I'd give it a try. If you don't try you won't know, right? I said if in three years I felt things weren't moving where I'd like them to, I'd move back to Japan."

Little did he know, a pleasant surprise awaited him not long after he started work at the University of Malaya, the country's oldest research university. It was at a 2014 meeting with officials from the Economic Planning Unit (EPU) in Putrajaya when the stars appeared to align. Dr. Shuhaimi and his colleagues from the university's commercialisation office were there to seek support to purchase a MOCVD reactor for LDMRC, as part of a high-impact research grant programme. Also at the meeting were representatives from CREST, together with Prof. Steven Denbaars from SSLEEC, who had lived in Penang during the earlier part of his career in the electrical and electronic (E&E) industry. They were there for initial discussions regarding the UCSB-Malaysia collaboration.

"Was I excited? Yes. Very excited!" Ever soft-spoken, Dr. Shuhaimi breaks into a smile when asked how he took to news of potential collaboration with Shuji Nakamura of Nobel Prize stature. The news was extra special for him, as his time in Japan had given him first-hand exposure to that country's solid state lighting industry and knowledge of its Hall of Famers, which included Dr. Nakamura.

There were two wins from that day: Dr. Shuhaimi's application for a MOCVD reactor was approved, and UM was introduced to CREST and their partners, which led to a formal invitation to join the Mirror Labs programme.

Echoing this excitement is the team from the Institute of Nano Optoelectronics Research & Technology (INOR) at Universiti Sains Malaysia in Penang. When word got out of the Mirror Labs and the opportunity to work with Dr. Nakamura and his colleagues at SSLEEC, the buzz was palpable.

"We were certainly excited, and seeing industry keenly advocate the Mirror Labs added even more optimism," shares Professor Zainuriah Hassan, the director of INOR.

When the Mirror Labs kicked off in 2014, INOR was on its own growth trajectory as a research organisation. More than ten years before, it had received RM22 million funding from the government under the Intensification of Research in Priority Areas (IRPA) programme of the 8th Malaysia Plan.

In 2014, the USM Department of Physic's Nano-optoelectronics Research and Technology (NOR) laboratory received government accreditation as a Center of Excellence in its field, recognition that also led to a change in name to INOR.

Under the Mirror Labs, INOR too has a MOCVD reactor of its own. Taking up space equivalent to about half a studio apartment each, the reactors were no small lab equipment. By deepening synergies with industry, the universities could then step into the horizon and discover the possibilities that abounded.

The spirit of the venture was "Factory Within a University." The prototypes to come out of the Labs would be studied, processed, and presented just as they would in industry, shepherded via collaboration and exchange with leading solid-state lighting companies operating in Malaysia, be they offshore locations of MNCs or homegrown SMEs.

The Mirror Labs connect University of Malaya, Universiti Sains Malaysia, Monash University (Malaysia) and Universiti Malaysia Perlis (UNIMAP) with UCSB in a grouping known informally as the GaN Diagonal. Dotting the western coast of Peninsular Malaysia and then extending across the ocean to California, the Diagonal can be called a shared science and technology undertaking nestled within the Pacific Rim.

Milestones from the Mirror Labs

The year is 2021. Through pandemic, political change, and the rhythms of research cycles, the Mirror Labs programme has made significant inroads in research and knowledge production in its first seven years.

Continuing the tradition of baking analogies, in 2016 the LED 'recipe' (the actual term in industry-speak) used by Dr. Shuhaimi's team successfully created the programme's first blue light gallium nitride LED. It was momentous, proof that Malaysian university researchers had acquired the exacting wafer epitaxy-growing skills and were well on their way to join the league of GaN researchers from more advanced countries. With the base recipe in their repertoire, the doors were open for the Malaysian team to improve and enhance their research until it reached industry-standard measurements of brightness, measured in units of lumens per watt.

And just as intended, these achievements were realised while maintaining steady cooperation with industry. As a result, goals were better aligned between academic and applied research.

“The Mirror Labs and the wider GaN programme provided us a golden opportunity to work with industry players. Any wastage of efforts and research hours was minimised. If before this, we only shared our research with industry further along the process, now the conversation is there from the start,” shares Dr. Norzaini Zainal, associate professor at INOR and lead researcher of a team currently working on developing LEDs that emit light in the ultraviolet range, a technology with the potential to play a big role in wide-scale disinfection.

Through lab visits, the UCSB professors assist their Malaysian collaborators with troubleshooting, optimising the set-up and maintenance of the reactors and fine tuning their epitaxy growth techniques. They also impart knowledge in areas which are less developed in Malaysia, such as etching and packaging of the LED wafers. To help with lift-off in the early years, postdoctoral UCSB researchers were assigned to the labs to provide guidance on handling the equipment.

Now, faculty members, Masters and PhD students, lab technicians and research officers all work on GaN technology. Occasionally, undergraduates are also taught to familiarise themselves with the MOCVD reactor, and how to produce the wafers.

In the Labs, one can find scientists trained in Japan, Malaysia, Singapore, Taiwan, the United States, and the United Kingdom. A passing observation by Dr. Norzaini captures the spirit of their collaboration, of how researchers are the products of their training and can arrive at teachable moments even in instances of disagreement.

“Dr. Shuhaimi and I, we always argue about how to grow the epitaxy layers. He’s a Japan graduate, so he carries with him that Japanese style, what I call trying everything to see what might work. As for me, having trained in the UK, that approach is unusual, because I was taught to simplify techniques first and only then attempt to build a solution,” she says in jest, but the fleeting insight lingers.

Dr. Shuhaimi has a ready answer when asked what he appreciates the most about the Mirror Labs programme: that it takes a chance on the Malaysian scientific community, and supports their endeavours.

“The opportunities accessed under the programme are once-in-a-lifetime. We get to work with international collaborators and really get our hands dirty with best-in-class equipment. And we are making progress at a global level. Maybe we are not at par with developed country researchers yet, but we are getting there. Malaysian researchers are capable, and with the right support we can make our mark.”

Escaping the Middle Income Trap

On a regular day, Datuk Yoon Chon Leong can be found in a spacious pre-war building in Georgetown’s core heritage zone, working at a non-profit that promotes STEM via hands-on learning among schoolchildren across Penang.

A business consultant, angel investor and educator, there is a nurturing side to his work following retirement from the LED industry. The local-yet-globally-integrated nature of the industry gives Datuk Yoon a broad perspective on ideal future-forward strategies for Malaysia to enhance the industry’s role as a key economic sector. It is wisdom he shares readily as co-chair of the CREST GaN Oversight Committee, which sets and executes the programme strategy according to its founding precepts of collaborative research and academia-industry alignment.

Looking back at the programme’s first five years, he can name clear wins. For starters, the epitaxy grown in Malaysian labs is as advanced as the ones grown in leading labs the world over. Added satisfaction comes in seeing all participants work together, flattening siloes as they proceed.

“To me, this programme is a game changer for Malaysia!” Datuk Yoon exclaims heartily, his eyes lightening up as they do whenever he speaks about entrepreneurship, tech, and talent development.

When asked to visualise the future, a time when today’s research gains have been steered toward wider economic benefit, he doesn’t skip a beat in responding. First to be tackled: the middle-income trap.

“Malaysia is now caught in the middle-income trap. Our local industry assembles the raw material from abroad mostly, and then manufactures and packages it. And that’s fine, it’s our strength based on our history. But in the future, we hope to change. Since the chips are the most value-added raw material in this industry, learning highly-skilled functions such as epitaxial growth is our gateway to becoming technology creators in our own right.”

The goal is to bring the technology closer to home, and embed it within local industry.

“When you know the technology involved, you can be more creative. You’re not forced to purchase the chips from commercial providers and adapt to them. In the future, our universities and local companies can co-design solutions. And given GaN’s potential in areas such as solid-state lighting and power devices, there is tremendous opportunity. We are localising materials science, which translates to deeper innovative capacity in years to come.”

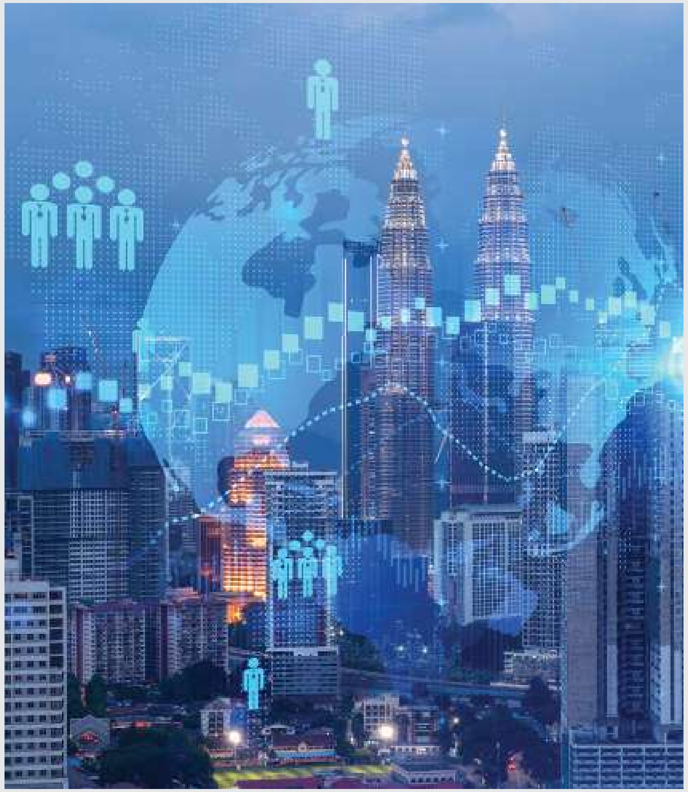
The future is never certain, but for Datuk Yoon—whose career essentially grew together with Malaysia’s LED industry—the broad contours are compelling.

“If we can reduce the technical barriers to commercialisation for our researchers and industrial product developers, and then let them build solutions and devices that fulfil market demands, we will be on our way to realising what we had set out to do all those years ago.”

In the world of semiconductors, the holy quadrangle of innovation is efficiency, brightness, size, and cost. If the locally-designed chips can hold their own in these aspects, Datuk Yoon is confident that they can be commercialised.

What timeframe would he go on the record with?

“Assuming the chips perform as well as I believe they can, I’d say five years. We just need to stay the course.”



CHAPTER 3

THE DOERS AND MAKERS: TALENT AND HUMAN CAPITAL

Imagine the year is 2030. Malaysia's profile as a site for GaN technology has gained industry recognition, even globally. In the job market, vacancy advertisements would feature roles unheard of just a decade before:

- Power device engineers, to design voltage systems that leverage GaN's ability to switch frequencies fast and thus save energy
- Epitaxial "crystal" growth experts, to fine tune recipes for LED chips that light up screens which display the sharpest images in the consumer market
- Principal investigators in labs that develop autonomous vehicles, building upon GaN's capabilities in radar detection
- Technicians in the maintenance and upkeep of various deposition reactors, such as Metal Organic Chemical Vapour Deposition (MOCVD)

Beginning in the Mirror Labs, knowledge of GaN and its application in areas such as 5G telecommunications, medical technology, and consumer electronics ventures beyond, looping in more universities and companies to steadily stretch the borders of the GaN Diagonal.

And things aren't confined to postgraduate level research in large universities. Modules in GaN applications are integrated into undergraduate programs across disciplines such as physics and industrial design, the early exposure creating a workforce ready for employment in different areas of design and development.

The start-ups of yesteryear are now homegrown multinational corporations (MNCs), serving a global clientele. Maintaining their high knowledge content activities onsite, these companies are moving the country out of the middle income trap (MIT). They play the long game of innovation, deepening the country's skills base while maintaining market leadership.

Aspirational as this description may be, it's a future being incubated right now.

The guiding question is: what does it take to build an industry? Foresight and resolve go without saying. And then of course, there is funding. But the secret sauce for sustainability and maturity is none other than a steady, skilled pool of human capital.

The talent development pillar of the GaN programme nurtures highly-skilled researchers via direct knowledge transfer from UCSB. There are two branches in this effort. First, sponsorship of Malaysian PhD students at UCSB. Second, shorter research attachments for Malaysian researchers from the participating universities. There is a steady stream of knowledge circulating within the GaN Diagonal, a back and forth of researchers to learn about the frontier and applied technology in the world of GaN.

13 : The number of visiting researchers and PhD students at UCSB since 2016

Areas of training:

- MOCVD Safety Requirements
- Epitaxy Growth
- Epitaxy Characterization
- Chip Design Simulation
- LED Chip Fabrication
- LED Packaging
- LED Testing

PhD: The Core Talent Pool

Opening the door to any Malaysian with at least a first degree in relevant STEM fields, the three-person cohort that was accepted into the PhD programme left for studies in 2016, and are scheduled to graduate by 2022. Upon their graduation, they will form a core component of growing Malaysia's name as a destination for investment in GaN.

Curiosity and a love of science led Clayton Qwah, Chow Yi Chow, and Ho Wan Ying to the PhD programme. They had combined work experience in large MNCs, university research labs and start-ups before taking the big step to apply for the PhD programme at UCSB, under CREST sponsorship.

Speaking from California in their penultimate year of their sojourn, the details they shared about their research provides an idea of what their roles could be post-graduation.

"The truth is, as remarkable as the science has been in advancing our understanding of LEDs, we actually don't know all that we can," explains Clayton. Classifying his PhD topic as "quite experimental," he delves into the science of LEDs layer by layer, literally. Focusing on a technique of epitaxy known as molecular beam epitaxy, he grows one layer of a LED at a time, testing it for voltages and currents to gain a sharper understanding of the processes that take place in each specimen.

On a similar track to understand the fundamental science behind GaN and other wide band gap semiconductors, Wan Ying's research is from the field of device physics. Deep diving into the materials that make up LEDs, she uses a technique called electron emission spectroscopy to study the band gap structure of materials such as GaN. "We 'pull' the electrons out of the layers to study their characteristics, which depend on many things, such as the type of material," she explains. In the longer term, this study of fundamental material characteristics can help identify a logical and rational way for companies to design future LEDs.

Counting himself very lucky for the access to first-rate equipment at UCSB, Chow Yi Chow works end-to-end in the device life cycle. He has the know-how to grow the crystals using Metal Organic Chemical Vapor Deposition (MOCVD) (the same technique conducted in the UM and USM Mirror Labs in Malaysia). After planning, simulation and then growing actual crystals using the MOCVD reactor, he processes the wafers into actual LEDs. “Think of it as a layer cake. Layer by layer, step by step, I’m making the cake and then testing its properties in areas such as power, efficiency, and wavelength,” he describes with aplomb.

Once they graduate, the trio will report for duty in Malaysia, where they are slated to provide the much-needed technical expertise to the technology community via CREST.

Knowledge Circulation within the GaN Diagonal

To widen talent diffusion in the GaN programme, shorter visiting researcher stints at UCSB are also offered to Malaysian researchers. For six months at a time, they participate in research, receive training on handling the equipment and take classes in areas of interest.

One of the participating researchers is Dr. Adreen Shah. A graduate from the government technical education stream who then pursued his first degree in pure physics at USM, he won’t soon forget the experience he gained at UCSB.

“UCSB was like a big GaN universe. From undergraduate to postgraduate, whether in the faculty of physics, materials science, computer science, or SSLEEC, everybody breathed and talked gallium nitride. It was fascinating, and a joy to be part of,” shares Dr. Adreen. During his six months at SSLEEC in 2017, his focus area was epitaxy. In short, he learned how to tinker around and troubleshoot the MOCVD reactor. Learning the inner workings of reactors also helped him identify the merits of different reactor set-ups and the trade-offs when choosing among them. Fresh from his PhD programme from University of Malaya’s Low Dimension Materials Research Centre (LDMRC), he is currently interviewing for engineer positions at large MNCs in Malaysia. His highly specialised, niche skills put him in good stead to secure a high-income job in the industry.

For many of the researchers, the accelerated learning at UCSB sparked ideas for deeper collaboration upon their return to Malaysia.

“The most important thing after receiving opportunities like this, is to give back when you come home,” shares Dr. Chang Wei Sea, senior lecturer at the School of Engineering, Monash University Malaysia and visiting researcher at UCSB in 2018. In her cohort at UCSB was Dr. Ng Shia Siong, associate professor at the Institute of Nano Optoelectronics Research and Technology (INOR) at Universiti Sains Malaysia (USM). When they returned to Malaysia, they decided to work together.

At UCSB, they leveraged the full suite of LED production equipment available and gained hands-on experience in the full chain process: fabrication of LEDs using an MOCVD reactor, characterisation, further testing in the ‘clean rooms’ and cutting and packaging.

In Malaysia, their collaboration lives true to the mission of the Mirror Labs: replicating and expanding the lessons learnt in California, within their own context. USM is the fabrication hub while Monash takes care of characterisation.

One of the first things Dr. Chang did was hire PhD students specifically to work on GaN. The extra hands on deck sped up their research, and her students were able to travel back and forth to USM to pick up fabrication know-how, allowing research to proceed even when Dr. Chang had to shift focus to teaching responsibilities when classes were in session.

Meanwhile, Dr. Ng recounts the snowball effect from the GaN programme, including the stint at UCSB.

Moving from Green to Ultraviolet:

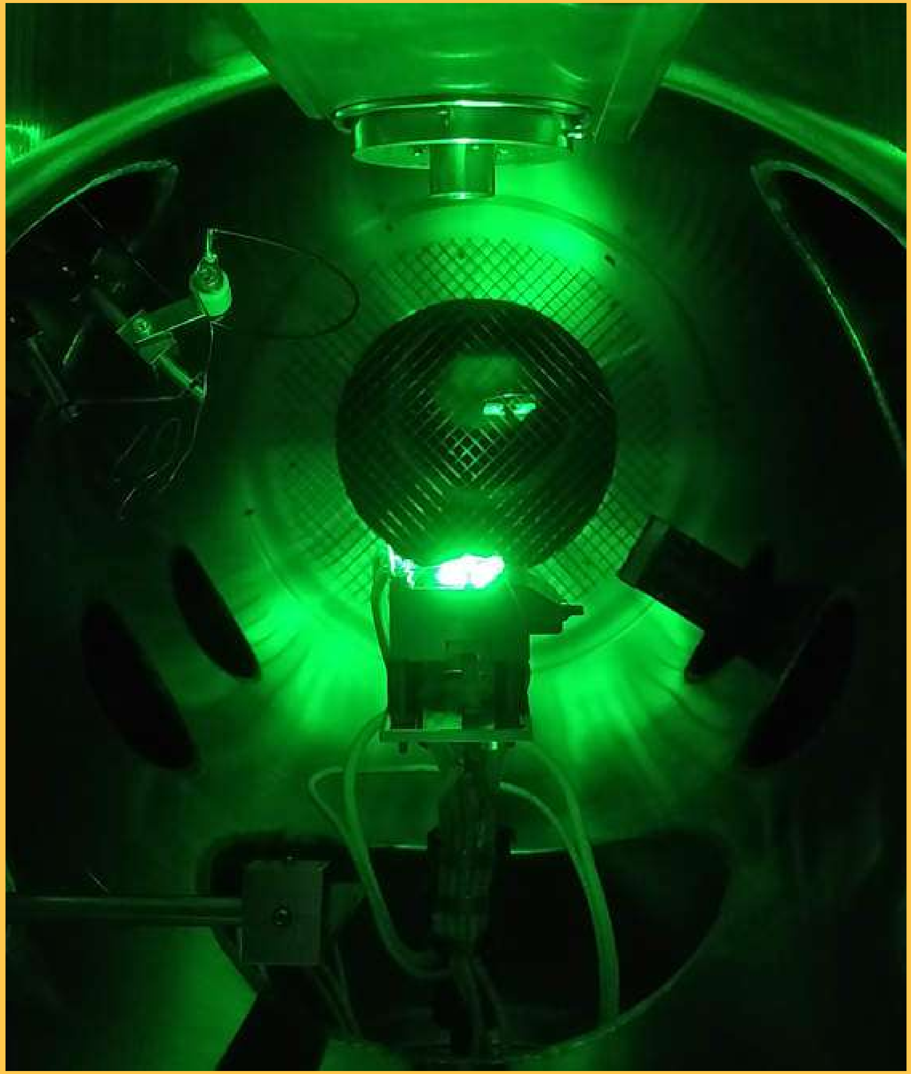
Dr. Norzaini Zainal

Credit: Dr. Norzaini Zainal

When it comes to explaining her research in layperson terms, Dr. Norzaini Zainal reaches for any analogy. Baking and even teh tarik-making make it into her explanation of her work as Associate Professor at the Institute of Nano Optoelectronics Research and Technology (INOR) at Universiti Sains Malaysia (USM).

"I'm eager for a challenge, like in research areas that are not well explored. The less it's explored, the more I'm interested," she says in sharing her motivation. This inquisitive spirit landed her on research teams working on developing green and ultraviolet (UV) LEDs at UCSB during her stint as a visiting researcher in 2016.

A day in Dr. Norzaini's life in the lab includes trying to grow green LEDs, which are known for being elusive compared to the red and blue LEDs that have already been adopted commercially. Green LEDs are the missing piece to the red-green-blue – commonly referred to as RGB – combination that produces the most efficient form of white light.



Credit: CREST

And then there are UV LEDs. For this, the type of UV sought is UV-C, the most energetic type of UV compared to its brethren, UV-A and UV-B. Coincidentally, the COVID-19 pandemic has led to more interest in UV LEDs due to the potential they hold in disinfecting and sanitising spaces such as operation theatres.

"In under 60 seconds, you can kill viruses on the surfaces. How amazing is that?" says Dr. Norzaini. Initially, the interest in UV LEDs was as a form of water sanitation in countries with unmet water needs. But now, the potential for medical disinfection has become more pronounced.

Chuckling at the heavily simplified example, she describes her lab's work as "making hybrids out of different ingredients."

The 'ingredients' are indium and gallium nitride (GaN) in the case of green LEDs, and aluminium and GaN in UV LEDs. There is plenty of trial and error to make sure the 'ingredients' meld together well.

"High quality GaN can only be produced at high temperatures. Indium can't take such heat and can just evaporate. Aluminium meanwhile requires higher temperatures than GaN, so they sometimes can be just 'disagreeable' all around," Dr. Norzaini explains.

Her passion for her research shines through. She credits her PhD students, Muhammad Esmed Alif bin Samsudin and Yusnizam bin Yusuf for their contribution in pushing their lab's research forward. Dr. Norzaini also has exciting news to share: in late 2021 she will begin a year-long fellowship at the prestigious Ferdinand-Braun Institute in Germany, under a scholarship by the German government. She will be working at the Materials Technology Department led by Dr. Markus Weyers.

She looks forward to the learning curve and what it means for her work upon her return, but ultimately, she shares the news to state a point.

"My story is an example of the GaN programme's benefits. If I had an interest in LEDs but no equipment or training to nurture it, I wouldn't have been able to progress as I have today. So, thank you."

"We don't stop at GaN, and see more research pathways opening up. We work on current and emerging GaN technologies including those relevant to the electric and electronics industry, and our knowledge in fabrication and characterisation has extended to other main applications and III-nitride materials. For example, Aluminium Nitride (AlN) as a potential source material for ultraviolet (UV) LEDs."

The Demand for Talent: The Industry Perspective

One thing that's clear is that "all this talent, and nowhere to go" won't apply to the talent produced by the GaN programme.

"There is no oversupply of talent. In fact, optoelectronics has tremendous room for talent absorption," says Dr. David Lacey, Director of Advanced Development & Services, R&D at ams Osram (Malaysia) and Board member of CREST.

As a senior industry member, Dr. Lacey has the long view of the industry's ups and downs to inform him. Less than a decade ago, the buzz was that optoelectronics would soon mature, its performance peaking and innovation reaching a dead end.

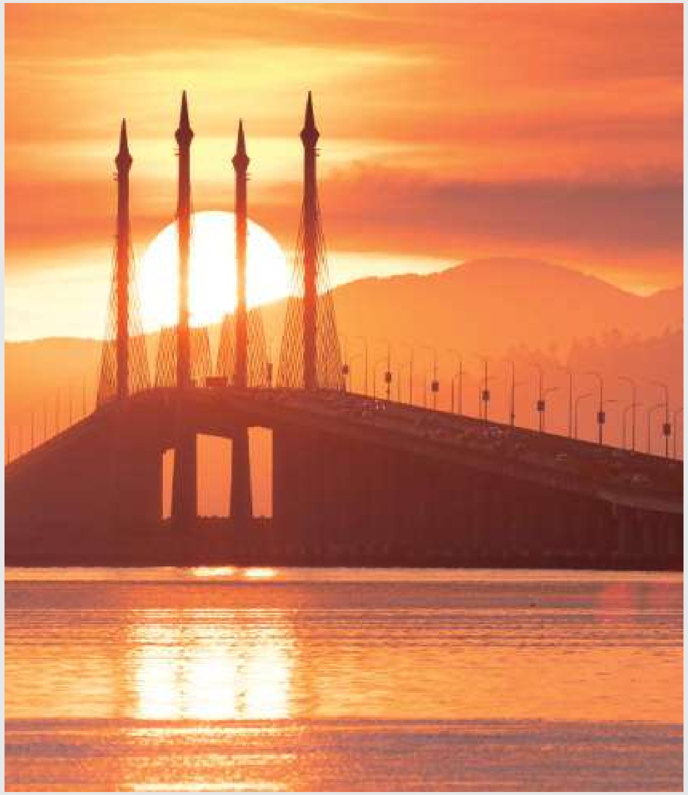
"But instead, we see the exact opposite happening. What happened was, lighting applications drove performance up and costs down, which suddenly enabled a vast array of new technologies to be developed," he adds.

"Internet of Things and the entire mobile lifestyle rely heavily on optoelectronics. Display technology, sensor technology, and autonomous vehicles are just a few areas where optoelectronics will continually expand."

The talent that emerges from the GaN programme is critical to companies like Osram. For example, the forecast supply of talent in the country was instructive in convincing the company's home office to approve additional investment in the country to build Osram's sprawling, state-of-the-art facilities in Kulim, Kedah.

And what can the bright minds who enter the industry expect, in terms of salary?

"In the semiconductor industry generally, for key positions in Asia, salaries are often higher than in Europe and the United States. A scarcity of skills means skilled and competent workers can expect to be generously compensated. I'd say engineers in this field are the highest paid in the country."



CHAPTER 4

LOOKING TOWARDS THE HORIZON

If you want to understand the future, look to the past.

As the curtains close on the pioneer phase of the GaN programme, the past five years offer fodder for rumination. Just as there are many reflections, there have also been bumps on the road, arming the team with wisdom in forging a future. Small wins are savoured, accompanied by the humbling realisation that they happened through the hard work of many parties.

Taking A Chance

“When we were just starting out in 2012, we identified possible areas of work. But when the opportunity to work with GaN appeared not long after, we saw its potential as a flagship endeavour for CREST,” shares Jaffri Ibrahim, CEO of CREST.

Instead of pursuing piece meal programmes with maybe one or two partners each time, the GaN programme allowed for something more all-encompassing that addressed primary research, talent development, and design and commercialisation in a single undertaking.

“It’s true that GaN is not the only programme that CREST, or Malaysia as a whole, needs. In this world, there are no silver bullets. But you have to take a chance on something, and really see it through so the industry moves forward,” adds Jaffri.

On a deeper level is the desire to do things differently, to break away from the unfortunate reality that many such catalytic programmes have been launched in Malaysia, only to meet an untimely end before they can even take flight.

Reflections

The speed to execute the programme’s key milestones did not match the urgency on the ground. This is a recurring theme in the team’s deliberations on aspects of the programme that could have been better.

The question whether expectations were too lofty or execution too draggy is moot. At times, getting the different parties to believe in the promise of the programme was a formidable task. A vicious pandemic didn’t help the situation either.

To illustrate, in the area of research, the targets set for LED brightness in the Mirror Labs was at 200 lumens per watt. Because of unforeseen issues beyond the team’s control, the research was stalled for a while. By the time things were reset and the research resumed, the world had moved on.

“Countries like South Korea, for example. They carried on while we had to go into down time. So when we finally reached 200 lumens per watt, researchers elsewhere were at 215 lumens,” shares Dr. David Lacey, Director of Advanced Development & Services, R&D at ams Osram (Malaysia) and CREST Board member.

If the actual events had kept pace with the ideal unfurling in Jaffri’s mind, after five years the incubation phase of the GaN programme would have ended, with the torch passed to private players.

“I had it in my mind that things would move ahead so fast, by now the programme would be under the helm of a few homegrown technopreneurs. It would have spun-off companies many times over, and the dream of forming a rich, catalytic industry would have moved full steam ahead.”

So, things are not as they could be in a perfect situation. However, nothing can deny the wins, the progress made in strengthening the research and talent ecosystems in the country, the building blocks to a robust industry.

The Wins

One obvious win: Malaysia is home to a bona fide GaN research fraternity, thanks to the GaN Diagonal that links the Mirror Labs and UCSB. In 2014, there were five researchers. In 2021, the figure is closer to 70 and still growing.

“Our counterpart researchers in the United States have told me that the industry is taking notice, recognising our universities as hubs of GaN research,” shares Datuk Yoon Chon Leong, an industry veteran with deep knowledge in the LED field and close collaborator of CREST.

The potential to flourish is apparent. CREST has it on good authority that its sponsored PhD students at UCSB are conducting research that may leave ground breaking impact on the trajectory of technology and innovation in their respective fields.

With regard to intellectual property, 10 patents are currently being filed in the major global jurisdictions. Only time will tell the gains they grant to the country’s inventors, but they are markers of accomplishment, even for those whose motivations are not very monetary.

“We know the road to commercialisation of our ideas is difficult. In fact, we don’t hope for it, because it depends on so many things beyond our control. The state of equipment, or whether there are collaborators to take our ideas to market, for example,” says Dr. Ahmad Shuhaimi Abu Bakar, the lead researcher at the University of Malaya’s Low Dimensional Materials Research Centre.

“But intellectual property is important to protect our ideas, which are the main output in our line of work. We do this to also show that yes, we are capable of conducting research of this standard in Malaysia.”

The Journey Continues

The next phase of the GaN journey is being formulated, but the broad contours are known.

The Northern Corridor Implementation Authority (NCIA) is the statutory body and strategic partner overseeing the GaN programme. As the government agency tasked with spurring economic development in the northern region of Peninsular Malaysia, known as the Northern Corridor Economic Region (NCER), their perspective focuses on the geographic reach and competitiveness of the NCER through initiatives such as GaN.

“The programme was established to accelerate the development of technical expertise in epitaxial growth and front end chip development in the industry, and to position Malaysia as a leader in new technology,” says Datuk Seri Jebasingam Issace John, Chief Executive of NCIA and CREST Board member.

“Although the semiconductor ecosystem was already well established, expertise was primarily centred on downstream activities. The guiding question was: how quickly could we get this technology into Malaysia and build the local talent base? It was an attractive and beneficial proposition; one that NCIA values in our quest to catalyse a world class economic region and technology hub,” he adds, providing the NCIA viewpoint.

The strategic collaboration between NCIA, CREST, UCSB, industry partners, and local research universities has borne fruit with significant results in intellectual property, locally developed epitaxy, GaN research talent as well as other spillovers from foreign direct investments.

Datuk Seri Jebasingam Issace John shares a few plans for the future.

“The next phase of the programme will focus on extending the programme to deeper applications of the technology into other industries such as power devices, smart agriculture, UV LEDs and micro-LEDs. This will lead to more value-added initiatives such as more filings of intellectual property; expert talent development which would lead to higher income jobs; the expansion of the Mirror Labs from academia to industry as well as commercial viability for the GaN technology created under the programme."

For CREST, the vision for the future involves formalising a collaborative model that commercialises research, to then feed back into the ecosystem by spurring GaN-like programmes in other areas.

The exact details are under wraps, but CREST confirms that discussions are underway with a local university to establish a spin-off company in the area of GaN power devices. They are seeking an arrangement where CREST and the university share ownership of the company, and CREST ploughs back part of its earnings towards kickstarting similar programmes in other fields.

International research partnerships will remain a feature of the programme. Discussions are ongoing with researchers who share an interest in academia-industry collaboration, to formalise an agreement where CREST can have access to their IP. A twin feature is for Malaysian researchers to be able to work with their international counterparts and develop next generation GaN-based devices.

Deepening the local talent pool and capabilities will take place at the research centres and facilities across all of CREST's partner universities (UM, USM, UNIMAP, and Monash). Operating according to the shared services model, the facilities will employ highly-skilled researchers that can work across programmes and serve the specialised needs of different clients. The idea is to provide a space for researchers to grow in their careers, by providing industry-relevant expertise that serves to boost Malaysia's stature as an investment destination.

In Search of a Success Story

The two keywords that describe the vision of CREST for the next phase of the GaN programme are success and replication. Success is the best way to convince others of the merits of what one does, while replication is a path towards making a bigger impact.

Success in this case is a spin-off company in the GaN technology space. It would leverage the research and knowledge from the GaN Diagonal, bringing together the universities and entrepreneurs. Aligned to the needs of its clientele, it would benefit from industry insight from CREST and its Board, a veritable brain trust with ready insight to the ways and means of industry and government.

As mentioned earlier, CREST and a public research university are currently in discussions to set up a company in GaN power devices. Could we be witnessing the early days of the coveted success story?

Not an outfit that counts its eggs before they hatch, CREST cannot offer a simple answer to this question. What they can do however, is articulate why they do what they do.

"We want to prove that the collaborative model can work. It's far from a perfect model, but it's a vision, and a vision must be broadly correct but topically refined as we go along. Collaboration has been the centre of what CREST does, and in this next phase of our growth we want to show that collaboration is the natural choice for any country with creator aspirations," shares Jaffri.

CREST might be squarely in the business of creating technology IP, but its model can be replicated elsewhere.

“Our domain might be in creating tech IP, but the same model can be used to build IP in areas like process, strategy, even people,” adds Jaffri.

“In my years doing what I do, I’ve observed that our society is too much a consumer of other people’s creations. I’d like us to become a society that generates our own IP, and I’m very confident that our people have all the skills, creativity, and passion to get there. What is needed is a platform for people to come together, to bring their best to the table and realise that the work they want to do is of value to their customers.

With this model, I hope young people with dreams would be able to fulfil their hopes to create their own thing—whatever that thing is—to make a difference in society, and the world.”

CREST