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EDITORIAL

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n early 2023, Gordon Moore, semiconductor industry pioneer, passed away aged 94. Moore entered a field where integrated circuits ran on peanut-sized transistors; seven decades after, his colleagues would unveil chips with nanometre-scale counterparts.

Moore predicted the industry would double the number of transistors on a chip at regular intervals, making computing more powerful yet compact. However, even as researchers pursued the challenge of ‘Moore’s Law’, some have looked beyond transistor scaling to boost the computer chip’s potential.

In our cover story, ‘The view beyond Moore (p. 10)’, A*STAR Research dives into research milestones in ‘More than Moore’ technologies at A*STAR’s Institute of Microelectronics (IME). From advanced chip packaging to silicon photonics, the feature reviews pivotal developments and partnerships that are continuing to shape innovative solutions for a data-hungry age.

While chips deal in digital data, they rely on other systems to translate information from the world around them. In our first feature, ‘Building tiny bridges to connect worlds (p. 20)’, IME senior researcher Yao Zhu discusses her team’s work in micro electro multi-physical systems (MEMS) and the value of industry collaborations in bringing innovations from lab to market.

In our second feature, ‘Computing at the speed of light (p. 28)’, A*STAR International Fellowship scholar Bowei Dong discusses the potential of photonics-based computer architectures that mimic the human brain, the challenges of new research frontiers, and his goals as a young researcher.

This issue also highlights new findings from A*STAR institutes ranging from advanced microbe-busting molecules to a predictive AI for critical wear on industrial machines. For more on these, turn to ‘Super surface sanitisers to the rescue (p. 04)’ and ‘The right time for a tool change (p. 26)’.

For more of the latest developments from A*STAR researchers, visit our website at research.a-star.edu.sg. You can also stay up to date by following us on Twitter at @astar_research, LinkedIn at A*STAR Research and Telegram at A*STAR Research.
Super surface sanitisers to the rescue

Safe for human cells but toxic to bacteria, fungi and viruses, a new strategy for sanitisising surfaces could give us the advantage in the fight against pathogens.

Even the cleanest-looking everyday surfaces such as phone screens and door handles can harbour a host of potentially disease-causing pathogens. Recent waves of global infectious disease outbreaks and increasing reports of antibiotic-resistant bacteria have proven the need to not just clean, but also effectively sanitise surfaces to stop the spread of disease.

Traditional chemical-based sanitisers don’t work universally against bacteria, viruses and fungi, and are particularly ineffective against sticky colonies of bacteria called biofilms. Yi Yan Yang, Institute Scientist at A*STAR’s Bioprocessing Technology Institute (BTI) and former covering Executive Director at A*STAR’s Institute of Bioengineering and Bioimaging (IBB), said a new class of molecules with unique properties may offer a new solution.

“Supramolecules are multi-component systems that can display multifaceted disruptive interactions against target pathogens like bacteria and viruses,” said Yang. The function of these synthetic materials is dictated by their molecular components, the arrangement of their individual chemical modules and the linkages that hold the entire system together.

Together with collaborators from A*STAR’s Institute of Sustainability for Chemicals, Energy and Environment (ISCE) and Fuzhou University in China, Yang and her team generated a novel class of antimicrobial supramolecules called guanidinium-perfunctionalised polyhedral oligomeric silsesquioxane (Gua-POSS). Gua-POSS features an inorganic core, flexible linkers and peripheral guanidinium groups (positively charged sections of molecules that disrupt cell membranes of pathogens).

“As Gua-POSS supramolecules act as a single species, their molecular structures are well-defined and characterised by a variety of techniques,” said Ning Li, co-corresponding author and a Senior
Structures of selected Gua-POSS designs with strong microbial activity. Each supramolecule has a polyhedral core of silicon (Si) and oxygen (O), with each Si centre linked to a guanidium group. The overall supramolecule forms a spherical shape with either eight or 10 guanidium ‘arms,’ enhancing their ability to contact and disrupt the surface membranes of microbes.

The team envisions the use of Gua-POSS and other next-generation supramolecules as potent sanitisers to keep surfaces pathogen-free and help stymie the spread of infectious diseases in the community.

Speaking about their next steps, Li said: “We are now building a library of guanidinium-perfunctionalised supramolecules with different geometric configurations, aiming to reveal the key design principles to achieve higher potencies.”

Researchers
Yi Yan Yang, BTI
and Ning Li, ID Labs

IN BRIEF
The complex supramolecule class called Gua-POSS features an inorganic core, flexible linkers of different lengths and peripheral guanidinium groups which help to destroy disease-causing microbes and disrupt biofilms.

Spotting the mechanisms of COVID-19 organ damage

A novel tissue-profiling approach provides new insights into the mechanisms of fatal COVID-19 by analysing different molecules and cell populations within organs.

Solving a crime often leads detectives to interrogate those who were involved to uncover the truth. With each lead they follow, the once-foggy details come into sharper focus, painting a more accurate picture of the events that took place.

Scientists have been on the tail of SARS-CoV-2 viruses to solve how some infections can trigger severe symptoms, like cytokine storms, which cause patients to go into respiratory stress and multiorgan failure. Despite the recent surge of infections in younger populations, the mechanisms behind severe illness in this group—particularly in those who have no pre-existing medical conditions—remain elusive.

Although studies are investigating organ-specific immune responses, Laurent Rénia, a Senior Fellow and Principal Investigator at A*STAR Infectious Diseases Labs (ID Labs), emphasises the need to delve deeper into the resident cells to gain an accurate understanding of how the disease develops.

“If you know the mechanisms involved in lethal SARS-CoV-2, you can develop specific therapeutic approaches,” said Rénia.

Teaming up with Lisa Ng, Executive Director of ID Labs; Akhila Balachander and Subhra Biswas from A*STAR’s Singapore Immunology Network (SIgN); and other collaborators from the National Centre for Infectious Diseases and the Health Sciences Authority in Singapore, Rénia led a study that utilised a novel tissue profiling technique the team developed called iSPOT. The researchers analysed autopsy samples from five young patients who succumbed to COVID-19 despite having no underlying medical conditions.

“iSPOT is a multiplex approach that allows us to look for multiple markers at once and also look for spatial interactions between different cells in a particular tissue.”

This highly sensitive technique enabled the team to analyse the stromal cells that maintain organ architecture, immune cell populations and cytokine levels in the tissues of the lungs, heart and small intestine.

The researchers discovered that all patients had a lower immune cell count and that lung and small intestine tissues displayed significant structural damage. The lungs and heart showed severe hyperinflammation, with high levels of the cytokine tumour necrosis factor alpha (TNF-α) and varying levels of interleukin 6 (IL-6), interleukin 10 (IL-10) and interferon-gamma (IFN-γ) among the five subjects.

These findings highlight that combining different cytokine-targeting therapies could help control cytokine storms and prevent fatal SARS-CoV-2 infections. Since their study, the team has patented the iSPOT technology and is currently refining it to better understand not only COVID-19 but also other diseases.

“The iSPOT technique is currently being improved by adding more immune and cell markers,” said Rénia. “This will allow us to refine the analyses for COVID-19 and other diseases such as cancer, where the mechanisms of immunopathogenesis remain poorly understood.”

Researchers
Laurent Rénia and Lisa Ng, ID Labs

IN BRIEF
The iSPOT technique shows that multiple cytokines contribute to damaging organs in severe COVID-19 cases, suggesting that combinational cytokine therapies could help prevent fatal infections.

Lingering viruses make tumours vulnerable

New associations between COVID-19 and immune responses in cancer patients reveal potential inroads to fighting tumours.

When ocean tides retreat, sea creatures can sometimes get trapped in pools on the rocky shore. Similarly, SARS-CoV-2—the virus responsible for the COVID-19 pandemic—can sometimes persist in the body long after symptoms subside, leaving the resident immune cells activated in a state of high alert.

Joe Yeong, Group Leader at A*STAR’s Institute of Molecular and Cell Biology (IMCB), said that this phenomenon may have important implications for patients undergoing cancer treatments that target the immune system. “What concerns us is that the tumour immune microenvironment can alter the efficacy of cancer treatments such as immunotherapies.”

Together with Mai Chan Lau, a Senior Researcher at A*STAR’s Bioinformatics Institute (BII), and IMCB Senior Research Officers Denise Goh and Jeffrey Lim, Yeong’s team forged a collaboration with international researchers involved in the Long Covid Autonomous Communities Together Spain (LongCovidACTS) study as well as researchers from the Duke-NUS Medical School, National Cancer Centre Singapore and Singapore General Hospital.

Through this programme, the team gained access to appendix, skin and breast tissue samples from two patients who were diagnosed with long COVID. Despite testing PCR negative for SARS-CoV-2, these patients exhibited prolonged and persistent symptoms 163 and 426 days after the infection’s acute phase.

Using spatial transcriptomics (ST), a sequencing technology that tracks changes in gene activity in intact tissues, the scientists aimed to gain insights into how tumour-associated immune cells might behave differently due to residual SARS-CoV-2.

“ST can detect tens of thousands of genes at one go from the same tissue section,” remarked Yeong, who added that the technique can also detect the presence of viral genes.

With liver and colon cancer patients who had previously recovered from COVID-19, the team’s analysis revealed active antibody-producing B cells in tissues with traces of SARS-CoV-2, which included the periphery of tumours. The gene activity in these immune cells suggested that an active defence response was still in progress.

Next, they investigated whether this buzz of activity might alter the degree of a tumour’s response to immunotherapy. The team generated predictive scores based on changes to immune gene activity. Surprisingly, they found that tumours harbouring residual SARS-CoV-2 could be more susceptible to the effects of immunotherapy.

The researchers hypothesised that a localised uptick in tumour-killing cells such as T cells and cytotoxic lymphocytes could potentially enhance the therapeutic effects of such cancer treatments.

According to Yeong, population-level studies could help clinicians hone in on cancer patients with long COVID who might respond better to immunotherapy. “I believe the findings have a huge impact on our understanding of virus-driven cancers such as some forms of liver, nose and cervical cancers,” concluded Yeong.

IN BRIEF
Spatial whole-transcriptomic analysis of cancer patients revealed that immune activity persists in tumour tissues months after COVID-19 infections resolve, which may enhance the effectiveness of immunotherapies.

Many New Year’s resolution diets fail because restricting calories can be difficult to maintain over time. However, nutrition experts now suggest that instead of eating less, simply changing the texture of food can help people maintain a healthy weight in the long run.

Processed, energy-dense foods like potato chips can be eaten much faster than healthier options like raw vegetables, making it easier to overconsume calories. Over time, this places people at a greater risk of developing obesity and poor heart health. Conversely, people at risk of malnutrition, such as the elderly, need palatable food that is easy to eat to meet their daily energy intake requirements.

A research team led by Ciarán Forde, a former Principal Investigator at A*STAR’s Clinical Nutrition Research Centre (CNRC) at the Singapore Institute of Food and Biotechnology Innovation (SIFBI), hypothesised that food textures such as hardness, chewiness and moistness could play important roles in shaping people’s eating behaviours.

The team, which included CNRC Research Officer Janani R and Senior Research Fellow Pey Sze Teo, had previously explored how calories consumed between fast and slow eaters differed. In their latest study, they demonstrated that combinations of food textures strongly influence our rate of eating.

To demonstrate the effect of individual texture combinations on eating rate, the team prepared carrots and crackers in different sizes and shapes, and with or without condiments (i.e. lubrication) before serving them to study participants to see how these factors influenced eating dynamics.

Based on the time spent chewing, the number of chews and the overall eating rates, the team found that single carrot pieces were faster to consume and carrots served with mayonnaise were easier to swallow.

“A key finding was that not all texture combinations have an equivalent impact on oral processing behaviours,” said Forde. Based on these and other findings, the team established a new hierarchy of effects, where food hardness had the greatest impact on eating rate in both carrots and crackers, followed by thickness, lubrication and unit size.
The various size, shape, hardness and lubrication (mayonnaise) combinations tested in the CNRC eating dynamics study. Carrots were chosen as an example of a high-moisture food with variable elasticity, while crackers were chosen as a low-moisture food with a hard, brittle texture and variable fracture properties.

Forde said that their findings can inform the development of new texture-based dietary interventions. “A combination of textures, rather than a single texture modification, could be applied to guide product reformulation and public health guidelines that slow the rate and extent of consumption.”

These findings also highlight how new approaches can help people manage their nutrition and wellness. The team is currently advancing their research through a collaborative study with the Division of Human Nutrition and Health at Wageningen University, the Netherlands, to explore the sustained impact of food texture manipulations on energy intake in the long run.

Researchers
Ciarán Forde, Janani R and Pey Sze Teo, CNRC, SIFBI

IN BRIEF
Modifying food textures to make them more crunchy or chewy influences eating behaviours and may be a useful, easy-to-implement tool to control long-term energy intake.

With its long-standing expertise and working partnerships, A*STAR continues pushing forward with chip technologies beyond the transistor scaling paradigm.
We live in the age of the integrated circuit (IC). Nearly 70 years after engineers first successfully embedded electronic systems into flat, two-dimensional (2D) ‘chips’ of semiconductive silicon, ICs have revolutionised our lives, putting computers into our hands, homes, workplaces and cities.

Since their invention, ICs have grown exponentially more powerful, energy-efficient, compact and affordable. In 1975, Intel co-founder Gordon Moore predicted the number of transistors per IC would double every 18 months. ‘Moore’s Law’ held for decades: in 1969, the Apollo 11 landed on the Moon using 30-kg computers with 17,000 transistors, each device worth today’s USD $1.5 million. By 2022, Apple’s USD $1,000 smartphones would hold chips with 16 billion transistors; handheld devices powerful enough to guide millions of Apollos, at a significantly reduced cost.

But scaling down has its limits; the rate thereof would slow down by the mid-2000s. “The smallest transistors today are measured in nanometres,” said Ping Koy Lam, A*STAR Chief Quantum Scientist. “The closer they get to the atomic level, the harder it is to keep their behaviour consistent. Atoms don’t obey macroscopic physics.”

Compounding the physical limits of Moore’s Law are economic ones. While downsizing was once a cost-effective way to enhance ICs, it now calls for increasingly complex and pricy processes. In 2020, McKinsey & Company reported that building a facility with 5 nm production lines cost roughly USD $5.4 billion; three times more than a 10 nm facility. Yet with the rise of technologies like artificial intelligence (AI), the Internet of Things (IoT) and high-speed telecommunications, demand for computing power is only set to accelerate.

To meet that demand, A*STAR research institutes such as the Institute of Microelectronics (IME) are looking beyond Moore’s Law for the future of chips. “There are still decades of growth to pursue in IC capabilities,” said Yee Chia Yeo, Assistant Chief Executive (Designate) of the A*STAR Innovation and Enterprise (I&E) Division. “While many technical challenges lie ahead, IME has ideas and solutions to advance much further. A key direction is ‘More than Moore’ (MtM): the integration of new functionalities that enhance IC performance, on top of transistor scaling.”

IME aims to facilitate advanced MtM technology development and commercialisation. “Since 1991, we’ve focused on high-impact R&D for the global semiconductor industry,” said Terence Gan, IME Executive Director. “Through strategic partnerships and tech advances, IME aims to push boundaries in this field to drive innovation and bring cutting-edge solutions to the market.”
BEYOND TWO DIMENSIONS

Advanced packaging is a key area of MtM innovation. Where conventional packaging aims to protect ICs from damage, advanced packaging aims to improve IC performance through how its components are connected and assembled; not just in two dimensions, but three.

“IME’s commitment to MtM is exemplified by our established advanced packaging line with High-Density Fan-Out Wafer Level Packaging (HD-FOWLP), 2.5D and 3D IC integration, and wafer-to-wafer and chip-to-wafer hybrid bonding capabilities,” said Gan. “This line has attracted R&D collaborations from various companies including integrated device manufacturers, fabless semiconductor companies, wafer foundries, outsourced semiconductor assembly and test providers, as well as materials suppliers.”

IME has a long history of collaborative research in chip packaging and taps into the strengths of other A*STAR research institutes such as the Institute of High Performance Computing (IHPC), the Institute for Infocomm Research (I2R), the Singapore Institute of Manufacturing Technology (SIMTech) and the Institute of Materials Research and Engineering (IMRE).

Beyond A*STAR, IME works closely with local and international universities such as the National University of Singapore (NUS), Nanyang Technological University (NTU), the Singapore University of Technology and Design (SUTD) and the University of Michigan, US. Through industry consortia, IME also partners with local and international industry players, starting with the first Electronic Packaging Research Consortium in 1995.

While initially focused on Moore’s Law-adjacent, single-chip packaging technologies such as flip chip, wire bonding, ball grid array (BGA) and copper/low-k, research soon shifted to MtM multi-chip approaches. What if, instead of increasing the number of transistors within an IC, you could package multiple ICs to act in concert?

“When IC technology nodes were around 40 to 28 nm, we started focusing on developing advanced stacking methods for 2.5D and 3D IC designs,” said Tai Chong Chai, a Principal Research Engineer at IME since 1993.

A breakthrough method that IME would delve into was the through-silicon via (TSV). Rather than using solder bumps or wire bonding to make electrical connections (interconnects) between two ICs, vertical channels could be directly bored through them. These would allow multiple ICs to be stacked vertically and assembled in three dimensions, with TSVs linking them as a single, more powerful device.

“We were one of the earliest research groups in the world to work on TSVs, forming our first TSV consortium in 2005,” said Xiaowu Zhang, a Senior Scientist II at IME. “We had the advantage of silicon etching capabilities and expertise in microelectromechanical systems (MEMS) that helped us with fabrication and testing.”

IME’s TSV capabilities would soon catch the attention of US semiconductor equipment manufacturer Applied Materials, which joined hands with IME in 2011 to set up the Centre of Excellence in Advanced Packaging. The joint laboratory, focused on wafer-level packaging (WLP), would be the first of several established with industry partners to develop further MtM technologies.

With end-to-end R&D and pilot production lines established, IME’s work would rapidly evolve over the next decade from enhancing MtM-related processes to developing a host of specialised, application-driven IC technology platforms.

“There are still decades of growth to pursue in IC capabilities.”

— Yee Chia Yeo, Assistant Chief Executive (Designate) of the A*STAR Innovation and Enterprise (I&E) Division
With 14 industry members, IME establishes a development line consortium and joint laboratory for high-density FOWLP (HD-FOWLP) capabilities in next-generation IoT technologies.

IME and Applied Materials open the Centre of Excellence in Advanced Packaging, combining IME’s 3D chip packaging R&D capabilities with Applied Materials’ equipment and process technology.

Two IME silicon photonics spinoffs are founded: Advanced Micro Foundry (AMF), a silicon photonics specialty foundry, and Rain Tree Photonics, a developer of optical transceivers for hyperscale data centres and 5G telecoms.

IME and Applied Materials launch their third phase of collaboration. IME establishes a system-in-package (SiP) consortium with four industry partners for heterogenous chiplet integration in 5G, AI and HPC applications.

BEYOND THE SINGLE CHIP

Apart from advanced stacking, another paradigm in MtM tech is the idea of heterogenous integration (HI). By fabricating and assembling a system of multiple, separately manufactured ICs and other components into a shared substrate, their functionality can be boosted for specific uses. For example, a multi-chip module designed for a mobile phone has a different set of ICs from a module designed for a self-driving vehicle.

“The benefit of the system-in-package (SiP), rather than the system-on-chip (SoC), is its modularity and versatility,” said Chai. “You can integrate chips or chiplets from different technology nodes, or radio frequency (RF) chips, sensor chips, and even MEMS.”

IME’s Advanced Packaging group has developed deep capabilities in the design, fabrication and assembly of various cutting-edge HI technologies. These technologies aren’t discrete; they can be combined to create customised solutions for various industry demands.

“Our advanced packaging line has enabled the realisation of novel IC packages for the mobility, IoT, power electronics and millimetre-wave (mmWave) markets,” said Gan. “Through our industry-grade equipment, intellectual property portfolio, end-to-end R&D and pilot production capabilities, we give innovators the necessary support to experiment, prototype and manufacture in small volumes.”

Some recent industry solutions developed at IME include 3D integration of different RF components such as filters, low-noise amplifiers or RF MEMS; 3D integration of piezoelectric micromachined ultrasonic transducers and multiple application-specific IC (ASIC) chips; silicon carbide interposers for high heat dissipation; and co-packaging of electronic and photon ICs using FOWLP.

In 2021, IME’s HI capabilities would lead to a consortium with industry partners Asahi Kasei, GlobalFoundries, Qorvo and Toray to develop high-density SiP with miniaturised RF front-end modules for 5G applications.

Applied Materials continues to be a key partner in IME’s advanced packaging R&D, with both parties recently signing an agreement for a five-year extension to their research collaboration. The partnership’s new phase will invest an estimated S$280 million to accelerate materials, equipment and process solutions for hybrid bonding and other 3D HI technologies.
MIX AND MATCH

With IME’s portfolio of MtM technologies, customised solutions often walk a tightrope between boosting computing power and the practicalities of production. “We can create novel processes, but if they’re not feasible, reliable or cost-effective, the industry won’t adopt them,” said Teck Guan Lim, a Senior Scientist in IME’s SiP group.

Three main HI platforms at IME include:

FOWLP
An advanced form of WLP where silicon wafers are diced into individual chips, then placed on a carrier, where they are overmolded and reconstructed into larger dies or modules with multiple layers of redistribution layers (RDLs) to electrically connect multiple chips. A lower-cost solution than 2.5D packaging, FOWLP’s applications include 5G/6G RF on mobile phones, Antenna-in-Package (AiP), automotive radar, augmented and virtual reality, and gesture sensors.

2.5D integration
The placement of IC dies side-by-side on a silicon interposer to approximate the benefits of an SoC. More powerful than FOWLP but more cost-effective than SoCs, 2.5D applications include high performance computing (HPC), network switches and network routers.

3D integration
The vertical stacking of IC dies to provide a shorter (and hence faster) interconnection. 3D integration can be done wafer-to-wafer or chip-to-wafer and is used in HPC, AI accelerators and other applications that benefit from higher speed and small footprints.

BEYOND THE ELECTRON

One more avenue of MtM research is the integration of photonic components within silicon ICs. Where electronic networks communicate with electric particles (electrons and holes), their photonic counterparts use light particles (photons).

“Compared to electrons and holes, photons offer several advantages including higher bandwidth, lower power consumption and an immunity to electromagnetic interference,” said Jason Png, Director of IHPC’s Electronics and Photonics Department. “Silicon photonics could lead to more efficient, versatile, and high-performance microelectronics systems through an approach outside transistor scaling.”

Using AI-powered modelling and simulation, coupled with optimisation techniques, IHPC has developed a library of passive and active devices to manipulate photons within circuits and interpret optical data into electronic forms. “These devices are capable of meeting high-performance requirements for low-loss, compact footprints and high speeds,” said Png.

Png added that some of this library’s more promising components have been experimentally validated by other A*STAR research institutes such as IME and IMRE; local educational institutions such as NTU, NUS and SUTD; as well as overseas collaborators.

With potential data transfer rates of 100 Gbps or more, photonics MtM might be a prime solution for fields that need higher-speed data transmission such as data centres, telecommunications and HPC. “Integrating optical interconnects in semiconductor packaging could boost chip-to-chip data transmission rates,” said Lim. “We are working on chip-to-chip communications using interposer waveguides.”

To date, silicon photonics development at IME has led to two spinoffs: Rain Tree Photonics, a developer of high-speed optical interconnects for data centre applications, and Advanced Micro Foundry, a dedicated silicon photonics foundry for innovative manufacturing solutions.
Apart from its R&D and pilot production capabilities, IME also supports ecosystem development initiatives to train the next generation of researchers in advanced IC technologies. “To develop and inspire future semiconductor leaders, we partner with the Singapore Semiconductor Industry Association (SSIA) on its talent development and outreach programmes,” said Gan. “We also encourage A*STAR talents to share their expertise and learn from global networking events, take advantage of sponsorships to pursue engineering doctorates and participate in SSIA’s leadership development programmes.”

Through its collaborations, educational initiatives, staff development programmes and sponsorships, IME remains dedicated to nurturing talent, fostering innovation and advancing the semiconductor industry in Singapore and beyond. “We strive to build a talented pool of professionals who can drive innovation, lead teams and contribute to the growth and competitiveness of the industry,” Gan added.

“As Singapore’s leading public agency for the advancement of impactful science, A*STAR looks forward to attracting new talents and working with new partners in academia and industry to bring MtM to greater heights,” said Yeo. ★

“We strive to build a talented pool of professionals who can drive innovation, lead teams and contribute to the growth and competitiveness of the industry.”

— Terence Gan, Executive Director at A*STAR’s Institute of Microelectronics (IME)
Unearthing skin-deep fungi

A new 3D-printed microneedle array could prove a more effective, less invasive diagnostic tool to extract disease-causing fungi from deep skin layers.

For some fungal species, living on human skin is like being on a tropical island vacation. The skin provides warm and moist conditions, and its natural oils contain abundant nutrients for fungi to feed on. While harmless fungi make up a small percentage of our skin’s natural microbiome, others can trigger problematic skin conditions such as athlete’s foot.

Diagnosing skin infections often involves doctors swabbing the affected site’s surface, stripping it with tape, or scraping it with a scalpel to sample its microbiome for lab tests. However, these methods don’t work well for some infections caused by fungi, which tend to thrive in the skin’s deeper layers.

“Currently, the only way to sample microbes from deep skin is a punch biopsy,” said Kun Liang, a Project Leader at the A*STAR Skin Research Labs (A*SRL). As such biopsies are both invasive and painful—performed by using circular incisions to remove skin tissue—dermatologists tend to default to skin scrapings for suspected fungal infections, which may not detect the real culprits at large.

Seeking a less uncomfortable option to sample the deep skin microbiome, Liang’s team joined forces with A*SRL Senior Principal Investigator Thomas Dawson and team, as well as clinical collaborator Hong Liang Tey from Singapore’s National Skin Centre (NSC). Together, they developed a transepidermal microprojection array (MPA), a 3D-printed device with tiny, needle-shaped structures to penetrate the skin and extract a fraction of the microbes beneath.

One major challenge was finding a balanced design that would reach deep enough to find suspicious fungi while minimising patient discomfort. “By making use of 3D printing’s rapid customisability, we fabricated a variety of MPAs with different geometries, heights, sizes and densities,” said Liang.

After extensive testing on skin models, the team landed on an optimal design. The prototype MPA was then tested on the scalps of healthy study participants and compared with tape and swab tests. They found the MPA was not only as sensitive as the two conventional methods, but it was also able to detect a greater variety of clinically-relevant fungal species that could cause disease.

With their sights set on commercialising the technology, Liang and colleagues are planning follow-up clinical studies at the NSC. They aim to compare the MPA’s efficacy with current clinical standards for skin sampling from patients with...
“Further studies are also needed to streamline and optimise the identification and analysis pipeline after MPA sampling to ensure a smooth transition to clinical use.”

fungal infections, with hopes that it may add to the dermatologist’s diagnostic toolkit in future.

“Further studies are also needed to streamline and optimise the identification and analysis pipeline after MPA sampling to ensure a smooth transition to clinical use,” said Liang.

The team also intends to explore the MPA’s unique capabilities as a research tool, using it to study the connections between its microbiotic samples and overall skin health.*

The 3D-printed microprojection array (MPA) designed to sample microbes from the human scalp at deeper layers than swabbing or tape stripping. The MPA is sized to fit in a single 2-mL Eppendorf tube for further DNA extraction processes.

IN BRIEF

When designed for balanced sampling efficiency and minimal pain, a transepidermal microprojection array outperformed traditional skin scraping methods in sampling clinically relevant deep skin fungi.

Getting to the root of hair colour

Scientists discover how a gene expressed in hair follicle cells controls hair pigmentation, creating opportunities for future skin cancer therapies.

The classic fairy tale of Rapunzel tells the story of a prince who saves a maiden trapped in a tower by climbing up her long hair draped out the window. The secret behind Rapunzel’s cascading tresses might be in her healthy dermal papilla (DP) cells—a group of specialised skin cells, located in the base of hair follicles, that regulate hair growth.

DPs also control hair pigmentation, a feature that interests Krystle Joy Ng, a Research Fellow at the A*STAR Skin Research Labs (A*SRL). Humans produce two forms of a pigment molecule called melanin to confer hair colour: the black-toned eumelanin that provides sun protection and the reddish pheomelanin. “Understanding the mechanisms that regulate the type of pigment produced can provide insights into therapeutics for skin cancers like melanoma," said Clavel. “There was a need to improve the currently available tools for studying DPs,” he explained.

In previous studies, Clavel’s team discovered that a gene called Sox2, which acts as a master regulator in DPs, influences several cellular processes involved in hair growth. Here, the team characterised the expression patterns of the leptin receptor gene (Lepr) which allowed them to target and track Sox2 activity in DPs over the hair follicle growth cycle.

Lepr’s unique capabilities made it highly valuable for demystifying the complexities of hair growth, said Clavel. “There was a need to improve the currently available tools for studying DPs,” he explained.

“We are now digging deeper into the molecular mechanism by which Sox2 controls melanogenesis in human skin.”

“Most conventional approaches cannot specifically target the DP from the moment hair follicles develop to the hair cycle stages during adulthood.”

Using a genetic tool called Cre-Lox recombination, the team eliminated Sox2 in Lepr-expressing mouse DPs, resulting in hair follicles producing lighter-coloured hair with less eumelanin and more pheomelanin. Additionally, they discovered that Sox2 regulates bone morphogenic protein (BMP) signalling, which controls the activity of pigment-producing melanocytes. Together, the team’s findings showed that DP cells not only control the choice of hair pigment, but also the overall production of pigment in hair follicles.

How DPs and other cells surrounding hair follicles regulate hair pigmentation has, until now, remained unclear. With the help of innovative genetic tools such as Cre-Lox, it’s becoming easier to connect the dots between the molecular pathways that control hair and skin colours, providing exciting new avenues for targeted therapies to treat and prevent skin cancer.

Moving forward, Ng and Clavel plan to use a similar strategy to probe other pathways governed by Sox2. “We are now digging deeper into the molecular mechanism by which Sox2 controls melanogenesis in human skin,” Clavel concluded.

IN BRIEF

The Sox2 gene in dermal papilla cells influences the amount and type of melanin produced in hair through associations with nearby melanocytes.

A highly efficient novel removal process of gossypol, a toxic compound in cottonseed meal, yields a pure protein product that meets food safety standards.

“Our protein extraction process reduces free gossypol levels to about 90 times below US Food and Drug Administration (FDA) permitted limits,” said Bi, who added that the purified CSM protein surpassed the nutritional value of pea protein and is predicted to be hypoallergenic.

“The next step forward will be to optimise and scale up the process for industry collaborations in the alternative protein ecosystem and to implement large-scale production of CSM protein-based food products,” Bi concluded. ★
BUILDING TINY BRIDGES TO CONNECT WORLDS
or most of us, our days revolve around high-tech digital devices. We navigate traffic with smartphones, monitor our health with smartwatches, warm up meals in microwaves and write emails on laptops. These devices rely on microelectronics: tiny electronic components, like computer chips, with individual parts that can be smaller than dust mites.

One key element of microelectronics is a group of components known as Micro Electro Multiphysical Systems (MEMS) transducers, which convert real-world phenomena like temperature, motion, acoustic signals and force into digital signals. MEMS transducers essentially bridge the real world and the digital, enabling devices to both understand physical conditions around them and process an appropriate response.

As Head of the MEMS Department at A*STAR’s Institute of Microelectronics (IME), Yao Zhu and her team focus on developing the sensors and actuators that enhance how MEMS transducers interact with their environment. These improvements could lead to more efficient, compact and affordable electronic devices—which could make a big difference for people who rely on medical devices like pacemakers for their daily lives.

In an interview with A*STAR Research, Zhu shares her thoughts on the future of IME’s MEMS team, as well as the need for collaboration between researchers and industry to bring microelectronic innovations more effectively from the lab into the hands of everyday users.

**Q:** **WHAT SPARKED YOUR INTEREST IN MICROELECTRONICS?**

Microelectronics has always fascinated me. The field plays a pivotal role in advancing so many industries: automotive, computing, communication, healthcare and more. The groundbreaking technologies of our time, including artificial intelligence, 5G communications, robotics and even quantum computing are all built on its foundation.

My curiosity about microelectronics was fuelled by the evolution of devices like laptops, smartphones and wearables that grow more powerful, intelligent and feature-rich each year. What captivates me the most about the field is its multidisciplinary nature: it brings together experts across electronics, physics, chemistry and materials science, providing endless learning opportunities.

**Q:** **TELL US ABOUT YOUR WORK IN MEMS SYSTEMS.**

Computers process information electronically, but the information in the real world exists in various non-electronic forms such as heat, motion, sound and force. MEMS transducers are a crucial link between the two worlds. Our work tries to address key challenges such as developing high-performance functional materials to build them with, and designing differentiated transduction structures that improve their sensitivity, selectivity and power efficiency.

We also strive to establish a versatile integration platform capable of hosting multi-physics devices and applications. We employ manufacturable semiconductor-based batch processes to produce thousands of miniature devices per wafer while ensuring controlled quality and cost.
“One example of an impactful research collaboration between our team and industry partners is the Lab-in-Fab project initiated in 2020 with STMicroelectronics and Ulvac Technologies.”

— Yao Zhu, Head of the Micro Electro Multiphysical Systems (MEMS) Department at A*STAR’s Institute of Microelectronics (IME)

**Q:** **WHY IS IT IMPORTANT TO WORK WITH INDUSTRY PARTNERS?**

Collaborations with them provide valuable insights into the potential impact and value of our tech, industry needs and the readiness of manufacturing technologies. They offer a practical perspective that goes beyond reading papers and market reports. Furthermore, industry partners can accelerate tech development and validate ideas through real-world applications.

One example of an impactful research collaboration between our team and industry partners is the Lab-in-Fab project initiated in 2020 with STMicroelectronics and Ulvac Technologies. In a traditional MEMS development model called ‘Lab-to-Fab’, a device concept is proven in a university or research institute’s lab, then transferred to a fabrication lab, or ‘fab’, for small volume production. However, this tech transfer can be challenging as mismatches between materials and tool sets can lead to years of redevelopment or revisions.

To address this, we introduced ‘Lab-in-Fab’, a new development model that accelerates the transition from proof-of-concept to a product by conducting both device R&D and small volume production under the same roof. In this model, our strong R&D team works closely with each customer to refine their device concepts; STMicroelectronics provides an experienced manufacturer’s feedback on its production feasibility; and Ulvac provides advanced equipment and processes for piezoelectric thin film fabrication.

So far, this collaborative model has been well-received by MEMS companies and researchers. As we enter the project’s second phase, we aim to further advance tech development and assist more MEMS companies in successfully bringing their products to market.

**Q:** **WHAT DOES IT TAKE TO SCALE UP RESEARCH TO COMMERCIAL MANUFACTURING?**

Assembling a strong team with innovative ideas and the ability to demonstrate them through experimentation is essential. However, transitioning from an innovative concept to commercial production can be a complex process with various challenges.

Designers must consider factors like product manufacturability, market potential, competition, customer requirements and regulatory aspects while developing a compelling value proposition. It is crucial to stay updated on the global market and tech trends to stay competitive.

Additionally, instead of focusing on single parameters or performance metrics, designers should ensure their final product meets a comprehensive set of performance requirements. Consider also the factors that will make mass production feasible, such as production costs, material availability and process complexity. The support of ecosystem partners such as A*STAR Innovation and Enterprise (I&E) can help connect designers with needed resources and expertise from industry and other institutions.

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WHAT ARE THE MEMS TEAM’S PLANS OVER THE NEXT FIVE YEARS?

Our goal is to establish Singapore as a global centre of excellence in piezoelectric MEMS technologies. We want A*STAR to be the industry’s preferred choice when developing new MEMS devices. To achieve this, we will continue to push the boundaries of piezoelectric functional materials; develop robust and versatile integration platforms; and showcase innovative reference designs.

A*STAR’s unique advantage lies in its comprehensive research capabilities, including MEMS device and process development from IME; new materials exploration from the Institute of Materials Research and Engineering (IMRE); and modelling from the Institute of High Performance Computing (IHPC). We will further enhance our capabilities within the agency and local universities while seeking collaborations with overseas universities. Working closely with strategic industry partners and staying updated on industry trends will be critical to our success.

WHAT ADVICE DO YOU HAVE FOR YOUNG RESEARCHERS LOOKING TO WORK WITH INDUSTRY PARTNERS?

Firstly, embrace early feedback. Seek it from industry partners to ensure your work aligns with real-world needs and challenges. Take it as constructive criticism as it will help you refine your ideas and focus your efforts on the most relevant problems.

Secondly, understand industry requirements. This includes its tech capabilities, market demands, cost considerations and competitive landscape. If you can align your research with their needs, you’re more likely to create impactful solutions.

Finally, be adaptable and flexible. Understand that an industry’s priorities and timelines may differ from academic settings. Be prepared to adjust your research focus, methodology or scope to align with their requirements if needed.

HOW MIGHT MICROELECTRONICS R&D ADDRESS CHIP SHORTAGES?

While there isn’t a straightforward solution to those solely through R&D, we can help alleviate them by attracting critical industry partners to Singapore through our world-class R&D capabilities. By adding value for our partners and fostering collaboration, we can strengthen the regional supply chain and mitigate disruptions. R&D can also play a role in exploring alternative materials, processes and design strategies that optimise chip production and enhance the semiconductor industry’s overall efficiency and resilience.
Say goodbye to plumes of dirty, carbon-filled smoke. When green hydrogen is burned as a fuel, it combines with oxygen from the air to produce energy, leaving only harmless water vapour as a byproduct. Unsurprisingly, sustainability experts have pinned their hopes on green hydrogen as a clean, renewable alternative fuel to serve carbon-intensive industries that are difficult to electrify, such as maritime shipping and steel production.

Creating green hydrogen involves the splitting of water molecules ($H_2O$) into hydrogen ($H_2$) and oxygen ($O_2$) using electricity in a process consisting of a hydrogen evolution reaction (HER) and an oxygen evolution reaction (OER). OER is typically considered the bottleneck of the whole process. In electrolysers, iridium-based catalysts have been shown to boost OER’s efficiency which can benefit large-scale commercial applications.

Jiajian Gao, a Research Scientist at A*STAR’s Institute of Sustainability for Chemicals, Energy and Environment (ISCE’), said that despite iridium catalysts’ potential, unresolved issues have stalled their widespread industrial adoption.

“The inadequate long-term stability and limited global reserves of iridium metal are the crux of the issue,” elaborated Gao. “To overcome these obstacles, it is essential to first step back and develop a holistic understanding of the current state of iridium catalysts, which will enable us to steer future research more effectively.”

Collaborating with colleagues from ISCE’ and Nanyang Technological University, Singapore, Gao explored the latest developments in the field of iridium catalyst research. Their goal was to showcase the diversity in emerging iridium catalyst structures and activity and understand how their chemical structures influence their activity and kinetics to steer the course towards better catalysts for OER.

Given the rarity of iridium, Gao predicted that catalyst formulations with significantly smaller proportions thereof will dominate the field in the coming years. “To achieve this, we must innovate designs that optimise the interactions between the catalyst, liquid solution and reacting intermediates during electrolyser operation,” said Gao.

The researchers discovered that a plethora of factors impacts the properties and performance of iridium catalysts. “Their shape, arrangement of atoms, and electric charge can influence their ability to conduct electricity, maintain stability and interact with water molecules during OER,” noted Gao.

Drawing on their insights from the review, the researchers suggested that a strategic choice of initial ingredients during the preparation stage is critical for optimising a catalyst’s efficiency. “We recommend materials that excel in conducting electricity and maintaining their structural stability,” added Gao.

In addition, they proposed that fine-tuning a catalyst’s internal environment where reactions occur, through the introduction of ‘dopants’, can also supercharge the OER. Together, these strategies may help create stable, durable and effective iridium catalysts for greener industrial practices.

Moving forward, Gao’s research team is taking a two-fold approach to transforming current practices for green hydrogen production. Firstly, they plan to design iridium catalysts that can be produced on a large scale. Secondly, they are working towards optimising the utilisation of the precious metal to minimise the amount needed, thereby making the entire process more efficient, sustainable and commercially viable.
The rhythm of life arguably starts with our heartbeat—whose constant pulsing changes tempo in response to our daily activities and emotional states. For people living with cardiac arrhythmias, or irregular heartbeats, this steady beat can change unpredictably with potentially dangerous consequences.

Despite being a leading cause of heart failure, cardiac arrhythmia has remained notoriously difficult to diagnose and prevent. However, a stem-cell breakthrough may offer some hope: skin cells from a patient can be chemically reverted to an embryonic stem cell state before being coaxed into heart cells. This ‘heart in a dish’ allows researchers to model heart physiology in a relatively non-invasive manner, and without the need for human embryos to be harvested.

The next hurdle is matching heart cell (cardiomyocyte) behaviour with disease risk, said Boon Seng Soh, a Principal Investigator at A*STAR’s Institute of Molecular and Cell Biology (IMCB).

“While some in vitro phenotypes have been linked with arrhythmia, we still lack a robust method for identifying key electrophysiological changes associated with heart conditions,” explained Soh.

Working with a team from the National University of Singapore, Soh and colleagues harnessed the power of machine learning (ML) algorithms to help bridge this gap and analyse large calcium-cycling datasets, a lab test used to assess the heart’s electrical activity.

The team first collected training data from human pluripotent stem cell-derived cardiomyocytes (hPSC-CMs) with a special reporter to visualise how calcium moves through the heart cell during contraction. They then input over 3,000 calcium-cycling data points collected from healthy and arrhythmic cardiomyocytes. Going a step further, Jeremy Pang, the lead author of the study, also trained binary classifiers to distinguish between specific subtypes of arrhythmia.

In their study, the scientists found that their ML algorithm could predict the presence (and subtype) of arrhythmia with over 90 percent accuracy. Soh said this predictive power could empower cardiologists to pick up on the condition’s early signs in patients long before symptoms manifest. “Using cardiomyocytes generated from human induced pluripotent stem cells, we potentially can predict the types of arrhythmias the person may develop years later.”

Additionally, ML-driven platforms could help accelerate the screening of medications for any potential toxic effects on the heart. Personalised testing of drugs on patient-derived cardiomyocytes could help avoid heart-related side effects.

Soh, the study’s corresponding author, said the team plans to tweak the ML platform to handle data from miniaturised heart tissue culture models. “We intend to adapt the platform to work with 3D-chambered cardiac organoid in vitro models which we have recently developed,” Soh said, adding that they also hope to apply ML to tackle age-related heart failure.

To catch a skipped beat

By analysing heart cells, a new machine learning algorithm could help predict arrhythmia risk before symptoms appear.
A novel machine learning model predicts wear and tear in manufacturing parts with less real-world data for cost savings and improved productivity.

Just as tyre treads wear out after years on the road, mechanical parts in manufacturing plants also suffer from the impact of wear and tear over time. Tool degradation is a problem in industrial settings because it can drive up manufacturing costs while diminishing product quality.

Machine learning (ML) offers a ray of hope for manufacturers seeking to optimise production lines. These platforms can learn from real-world data to predict the ‘sweet spot’ when manufacturing parts need to be serviced or replaced to maximise their lifespans without affecting product quality.

Amirabbas Bahador, a Product Development Scientist at A*STAR’s Advanced Remanufacturing and Technology Centre (ARTC), said that a specialised technique called transfer learning offers advantages over traditional ML methods for tool wear prediction.

“Transfer learning is done by starting from previously-learned patterns, instead of starting the learning process from scratch, saving significant amounts of manufacturing time and costs,” explained Bahador.

A group led by Bahador and Chunling Du, a Scientist at ARTC, combined transfer learning, low-cost sensors and one-dimensional convolutional neural networks to develop a first-of-its-kind tool wear prediction model.

In their study, the researchers tested their transfer learning system using two types of low-cost, microscale sensor-incorporated accelerometers: a microelectromechanical system (MEMS) and an integrated electronics piezoelectric (IEPE). These sensors detect linear motion, acceleration and shock in the machines they are attached to.

As the MEMS accelerometer was a single-axis accelerometer with limited capabilities, the transfer learning model significantly increased the tool wear detection accuracy using the MEMS accelerometer from 58 to 85 percent.

By leveraging knowledge gained from previously learned tasks, transfer learning was able to improve the accuracy of the tool wear detection model and reduce
The tool wear classification model’s architecture, based on a one-dimensional convolutional neural network (CNN) and full connection layers. The model was pre-trained on a HAAS ST-10 lathe machine; CNN layers were then frozen and transferred to build a model for a NLX2500 TurnMill lathe machine. As a result, far less training data was needed to sufficiently train the new model to an 80 percent accuracy level.

The amount of data required for model development. The team reported that their platform maintained high accuracy levels of 80 percent and above, even with up to 80 percent less training data.

Bahador said that developing the transfer learning model was no small feat: “The biggest challenge in designing the transfer learning model was selecting the number of layers required to be fixed or frozen from the source model, so that the transfer learning would have a high accuracy.”

The study’s success proves the utility of transfer learning for the manufacturing industry and even other sectors such as finance, marketing and transport navigation systems. The team is continuing to push the limits of the technology for manufacturing applications.

“My next research focus would be to apply similar ML and transfer learning techniques to additive manufacturing process monitoring and powder characteristic evaluations,” concluded Bahador.

Researcher
Amirabbas Bahador,
ARTC

IN BRIEF
The transfer learning approach uses a one-dimensional convolutional neural network which maintains high accuracy for tool wear detection systems even with 80 percent less training data versus conventional techniques.

COMPUTING AT THE SPEED OF LIGHT
The human brain is often compared to a computer. Using electrical impulses, it receives inputs from the external world, integrates this information in a split second, and plans and executes responses. The brain’s immense information processing capabilities have also inspired the design of high power computing architectures and driven the development of artificial intelligence (AI) and machine learning systems.

For decades, devices like transistors and semiconductors that operate using the humble electron have dominated the computing world. However, as researchers begin to hit physical limits in how much processing power they can fit into an electronic chip, some are exploring new ways of building chips to overcome those limitations.

One solution might lie in chips that use a different signaling medium altogether: the photon particles of light, instead of the electrons of electricity. Similarly inspired by the brain’s architecture, photonic neuromorphic computing is an emerging approach that could provide unparalleled data transfer bandwidth and minimal latency compared to electronic computers, according to Bowei Dong, an A*STAR International Fellowship (AIF) scholar at Oxford University in the UK.

Ahead of his return to A*STAR, Dong delves into the challenges and opportunities in photonic neuromorphic computing and how the dynamics of light could revolutionise the next generation of computing technologies in this interview with A*STAR Research.

Q: WHAT SPARKED YOUR INTEREST IN PHOTONICS?

My first exposure to research was at the Femtosecond Dynamics lab at Nanyang Technological University, Singapore. Their work ignited my fascination with the capabilities of light. I was especially captivated by the ultrafast dynamics of light-matter interactions, which enabled the study of physics at one-quadrillionth of a second.

Over time, I’ve also seen the rapid growth of AI and its incredible capacity to assist with various human activities. Given the need for ultrafast processing in AI models, I’m convinced that photonics could excel in this area by providing ultrafast information transfer and parallelised operations. This belief has fuelled my ever-growing interest in photonics and continues to drive my passion for uncovering its full potential.

Q: HOW HAS A*STAR SUPPORTED YOUR SCIENTIFIC JOURNEY?

With the A*STAR Graduate Scholarship, I pursued the Integrative Sciences and Engineering PhD Programme at the National University of Singapore. This unique programme exposed me to many fields, equipping me with interdisciplinary research capabilities that I find indispensable today, especially in a field as complex and multifaceted as photonic neuromorphic computing.

During my PhD training, I was also attached to A*STAR’s Institute of Microelectronics (IME), which allowed me to interact with and learn from the institute’s deep talent pool.

Following my PhD studies, I was fortunate to receive AIF’s support to pursue my passion and broaden my horizons through overseas postdoctoral research. The international setting taught me critical lessons on conducting high-quality research and helped me establish a strong global network that will be invaluable in future.
How might photonics help address the limits of electronic processors?

There are innovations in electronic computing architecture that provide promising solutions, such as electronic neuromorphic computing, which essentially boosts what processors can do by modelling their architecture after the human brain. However, our work explores a fundamentally different approach to computing—using photons, not electrons, as information carriers.

Photonic computing offers several advantages over electronics, including a much larger computing bandwidth. Electronics can access a maximum bandwidth of around 50 GHz, equivalent to <1 nm in photonics, whereas the visible light spectrum alone spans 400 to 700 nm. Moreover, photonic computing experiences significantly lower latency; where data transfer in large graphical processing units can take up to microseconds per operation due to capacitive delay, photons are several-fold faster since they transmit at light speed.

Most importantly, unlike electrons that interact with each other, photons transmit independently. Each photon also bears multiple degrees of freedom (e.g., wavelength, polarisation and mode), allowing it to convey abundant information. By parallelising photonic computing across these degrees of freedom, we can derive exceptionally high computing throughput and thus address the limits of transistor scaling that Moore’s Law describes.

Photonic neuromorphic computing takes these advantages a step further; by changing both the computing architecture and the information carrier within a system, one can enable it to compute like the human brain, but at the speed of light.

Q: Bowei Dong

A*STAR scholar
A*STAR International Fellowship (AIF)

www.research.a-star.edu.sg
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**Q:** WHAT TIPS DO YOU HAVE FOR A PRODUCTIVE RESEARCH OUTPUT?

Be open to discussions, embrace interdisciplinary research and explore diverse fields. Keep thinking about how your expertise can make a difference and contribute to the work of others. It’s important to step out of your comfort zone regularly; look into different fields where one can complement or apply cross-disciplinary research. Some out-of-the-box solutions may come from people without much prior knowledge in a specific area.

It’s worth noting that publication output can vary significantly depending on the nature of one’s research. Some research focuses more on prototyping and industrial applications, with results presented to industrial partners instead of academic societies. In my case, exploring new computing paradigms requires frequent communication with the academic community to gain their feedback, which could lead to many publications.

**Q:** HOW DO YOU TACKLE COMMON CHALLENGES IN YOUR FIELD?

Because photonic neuromorphic computing is still in its infancy, there are many technical challenges in developing its technologies, such as the on-chip integration of high power laser arrays and computing architecture optimisation. However, each challenge is also an opportunity for innovation. By focusing on a very specific challenge, I can come up with different ideas to potentially solve it, while considering what resources and approaches I can use to realise those ideas.

Moreover, such research is highly interdisciplinary; it sits at the intersection of photonics, electronics, computer sciences, mathematics and materials sciences. I often need to learn the fundamentals of other fields, enabling me to better collaborate with experts and understand their perspectives. Fortunately, working in an environment like A*STAR with its diversified talent pool provides me with access to a broad range of expertise.

That expertise is especially important as we deal with very complex systems. Problems and errors can come from anywhere and occur at any step, making troubleshooting difficult. As such, having the patience to break down complex systems into smaller components is essential. Experience also plays a crucial role, so expanding my network to consult with veteran experts is highly beneficial.

**Q:** WHAT DO YOU HOPE TO ACHIEVE AS A YOUNG RESEARCHER?

I think Singapore holds immense potential to excel as a global leader in photonic neuromorphic computing. A*STAR’s talent pool is capable of addressing various challenges related to computational architectures, algorithms and functional materials. Additionally, Advanced Micro Foundry, an A*STAR spinoff, leads the way in photonic integrated circuit prototyping.

My objective is to contribute to this mission by showcasing a prototype that outperforms existing state-of-the-art solutions. This would prove the viability of photonic neuromorphic computing as the optimal path forward, realising a paradigm shift towards next-generation computing. If successful, my long-term aspiration is to help establish a dynamic platform for this field of research in Singapore. ★

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Machine learning models graduate to the real world

A new framework gives pre-trained machine learning models the ability to perform optimally in real-world settings, even with limited training data.

How do you train a self-driving car to make an emergency stop when a pedestrian dashes across the road? Training data used to prime the vehicle’s machine learning (ML) algorithms might include video footage of a similar scenario. However, with infinite variables from weather conditions to traffic behaviour, it’s impossible to cover all bases during machine training.

To perform well in these dynamic real-world situations, ML models require an abundance of high-quality training data, which experts say isn’t always easy to acquire. “Real-world data collection can be difficult, time-consuming or expensive; and we cannot capture all variations in the training dataset,” explained Wenyu Zhang, a Research Scientist at A*STAR’s Institute for Infocomm Research (I²R).

The difference between situations captured in training data and all possible real-world scenarios is known as a domain shift, which is addressed using source-free domain adaptation (DA) to help algorithms adapt in unfamiliar circumstances. Traditional DA either requires impractical amounts of training data or adopts potentially unreliable learn-on-the-fly approaches—neither are ideal for applications with large domain shifts.

Zhang and colleagues proposed a more flexible, less data-heavy solution leveraging batch normalisation: a technique conventionally used to improve the performance of deep learning neural networks by reducing overfitting, increasing their learning rates and improving their generalisation capabilities.

The team implemented small changes to the batch normalisation layer of the neural network architecture which helps algorithms adapt to real-world information rather than relying primarily on training data. Their few-shot DA framework optimises feature normalisation statistics in pre-trained models with a small target domain support set—a method the team found to be accurate and reliable across multiple datasets.

As a proof of concept, the researchers tested their DA framework using image data that exhibited various types of domain shifts ranging from different art styles to pictures of objects photographed in different environments. They found that their approach could adapt to various domain shifts with ease and perform without extensive real-world training.

“We demonstrated its effectiveness in image classification and segmentation across several publicly available datasets,” said Zhang, adding that the team is aiming to expand the DA framework for use with other network and data types.

Step into a high-end restaurant or bar in the city and you might see a mixologist in action, whipping up colourful concoctions of masterfully blended liqueurs. Cocktails and alloys have a lot in common—they’re both mixtures of different components in set proportions which produce a specific flavour (or function).

Among alloys, high entropy alloys (HEAs) are particularly complex cocktails. Where traditional alloys might just blend two metals, HEAs can involve five or more, blended in roughly equal proportions. This complexity can give them exceptional strength, durability and corrosion resistance.

Naturally, a challenge materials scientists face is figuring out which metal combinations create HEAs with favourable physical properties. “HEA design spaces are incredibly vast. Once you’ve chosen the metals involved, there can be over 100,000 feasible compositions to investigate for the best options,” explained Viacheslav Sorkin, a Senior Scientist at A*STAR’s Institute of High Performance Computing (IHPC).

For instance, the same five metals in a quinary HEA might be combined in over 7,000 possible patterns. Vary their concentrations and this number skyrockets, dragging out HEA design and development timelines. “Existing computational methods to screen HEAs are either lengthy and costly, or trade accuracy for efficiency,” Sorkin added.

One such method is the small set of ordered structures (SSOS). Imagine floor tiles with the same geometric pattern: by studying one tile, you can surmise the larger patterns a roomful of them might create. Likewise, SSOS works out a HEA’s physical properties—such as stability, formation energy and mass density—by simulating small, repeating three-dimensional sections within the alloy, instead of modelling every atom inside.

“While SSOS is currently considered the most promising way to accurately screen many HEA candidates at once, it still involves a relatively huge design space and expensive calculations, making it lose efficiency,” said Sorkin.

To improve on SSOS, Sorkin and colleagues developed the Preordered SSOS (PSSOS) method which selects feasible options from a ‘pre-optimised’ library of HEA structures identified through extensive screening and Density Functional Theory (DFT) structural simulations.

Using a quinary AlCoCrFeNi HEA as a test case, the team reported that PSSOS was more efficient and as accurate in predicting stable HEA compositions as the special quasi-random structures (SQS) method commonly used in HEA design today. The method also shrunk a design space of around 50,000 feasible SSOS structures into just 1,000.

“PSSOS significantly outperforms SSOS in efficiency, bringing high-fidelity, high-throughput HEA screening closer to reality,” explained Sorkin.

The method can pave the way for developing advanced HEAs in challenging industrial applications such as biomedical materials and extreme-temperature coatings. Sorkin’s own team is currently working on applying PSSOS to streamline the production of lightweight HEAs.

“It’s one of the hottest research topics in metallurgy,” said Sorkin, adding that such next-generation HEAs might one day outperform traditional aluminium and titanium-based lightweight alloys. ★

Researchers
Viacheslav Sorkin and Yong-Wei Zhang, IHPC

IN BRIEF
To identify optimal ‘recipes’ for high entropy alloys, the Preselected Small Set of Ordered Structures method quickly and efficiently calculates the formation energies and mass densities of different metal combinations.

Biomolecules dance in the light

An innovation in flexible light-emitting capacitor technology visualises biomolecules for next-generation healthcare devices.

Forget wires and bulky machines—with advanced healthcare technologies, your watch can track your heart rate during your workout. Soon, thinner, lighter and more flexible wearable devices may be on the way thanks to a class of electronics called flexible interactive displays, or FIDs. Unlike conventional displays, FIDs can be bent or curved without losing functionality, offering unprecedented possibilities from soft robots torollable screens.

The team led by Xiaoying Qi, a Scientist from A*STAR’s Singapore Institute of Manufacturing Technology (SIMTech), and Kanyi Pu, from Nanyang Technological University, Singapore has been developing FIDs for healthcare applications. They created the Biomolecule-Interactive Flexible Light Emitting Capacitor Display (BIO-LEC), a device which ‘reads’ biomolecules in a dynamic way and displays the information on a glowing screen.

“Our BIO-LEC is designed to provide a local, dynamic, quantitative and instantaneous visualisation of biomolecules through a naked-eye detectable electroluminescent emission,” Qi explained.

The BIO-LEC consists of two parts: a light source, and a sampling compartment made up of a microfluidic chip. The display is designed to accurately measure biomolecules in real-time without any special labelling or preparation.

Qi said other development considerations were that the BIO-LEC should be easy and cost-effective to manufacture at large scales and should be sensitive enough to pick up even trace concentrations of a target biomolecule.

In their study, the group successfully demonstrated that BIO-LEC could accurately track heparin concentrations in a series of test simulations. Heparin is a drug commonly used to treat and prevent blood clots.

“Over 500 million doses are prescribed worldwide each year,” said Qi. “Heparin needs to be administered within a certain therapeutic window and is the second most common medication error in intensive care units.” The team’s success demonstrates BIO-LEC’s potential utility in real-time monitoring and measurement of medication levels in patients.

Moreover, BIO-LEC is relatively easy to manufacture and more flexible compared to conventional FIDs. Instead of mounting rigid electronic components onto printed circuits of flexible substrates, BIO-LEC uses a different production process.

“BIO-LEC manufacturing is based on the principle of inorganic phosphor powder-based LEC display with add-on top microfluidic sampling function, which possesses the simplest printable multilayering device feature,” said Qi.

Qi elaborated that the group is motivated to expand the targets detectable by their BIO-LEC by tweaking the dielectric properties of the device’s top electrode. They are also experimenting with various assembly features for the BIO-LEC in up to three dimensions. “All these parameters are interesting and are worth exploring,” Qi added.

“Our BIO-LEC is designed to provide a local, dynamic, quantitative and instantaneous visualisation of biomolecules through a naked-eye detectable electroluminescent emission.”

IN BRIEF

The Biomolecule-Interactive Flexible Light Emitting Capacitor Display (BIO-LEC) uses microfluidics to turn biomolecule detection into readable light signals, enabling advances in healthcare electronics, human-machine interfaces and soft robots.

Safer landing for jet engine alloys

By revealing how a high-performance aerospace alloy deforms under stress, a new computational model creates opportunities to improve its design and broader industrial usage.

What do jet engines and spiderwebs have in common? They’re both made of remarkably strong yet lightweight materials. Spider silk is one of nature’s strongest and toughest fibres, woven from flexible, interconnected protein chains to create delicate threads stronger than steel.

In some ways, lamellar titanium aluminide (TiAl) is the aerospace sector’s spider silk: formed from alternating nanometre-thin layers of both metals, it’s a light and durable alloy with a high strength-to-weight ratio. Lamellar TiAl stays strong even at extreme temperatures, making it a good choice for jet engine parts that heat up while operating, such as turbine blades.

However, at room temperatures, lamellar TiAl lacks ductility; compared to more common alloys like steel, it’s brittle and prone to cracking, explained Balaji Selvarajou, a Scientist at A*STAR’s Institute of High Performance Computing (IHPC).

“The main hindrance to lamellar TiAl’s wider adoption is its low damage tolerance,” Selvarajou commented. “In steel, even if microscopic cracks form during fabrication or operation, it takes a considerable amount of force to propagate them. However, with lamellar TiAl, these cracks can grow with very little extra loading.”

This means making crack-free components from lamellar TiAl is difficult and expensive. Currently, the alloy is a viable material only for manufacturers who can absorb high costs, such as the aerospace and automotive industries, Selvarajou added.

Aiming to understand why lamellar TiAl tolerates damage poorly, Selvarajou and colleagues teamed up with the School of Materials Science and Engineering, Nanyang Technological University, Singapore, to design a study that investigated the different mechanisms involved when the alloy deforms. They developed a computational model that simulates how the alloy behaves under stress based on its microstructural features and external environment.

The computational model was powered by crystal plastic finite element modelling (CPFEM), which tracks microstructure formation under a range of loading forces and temperatures. To build the model, the researchers gathered published data on TiAl alloys fabricated under a wide range of experimental conditions.

“CPFEM allows us to incorporate both the effects of individual deformation mechanisms, and the interactions between them, on the alloy’s mechanical responses,” explained Selvarajou. “It captures all key aspects for deformation modelling including anisotropy, temperature and microstructure effects.”

Based on their simulation data, the researchers recommended adjustments that may improve lamellar TiAl’s hardness, such as introducing trace elements or heat-treating the alloy before shaping. In addition, their work also overturned a common assumption in the field.

“It’s widely assumed that one way to increase TiAl ductility is to decrease the lamellar width,” said Selvarajou, referring to the distance between the alloy’s alternating layers. “However, we found that beyond a specific critical value, a thinner lamellar width doesn’t improve damage tolerance.”

The work creates the foundations for stronger future TiAl alloys that can be used in landbound industries such as nuclear power and chemical processing. “We would consider our work a success if it inspires other follow-up studies that help evolve lamellar TiAl into a widely used structural material,” said Selvarajou.

Researcher
Balaji Selvarajou,
IHPC

IN BRIEF
Crystal plastic finite element modelling simulated the structural mechanics of microscopic fractures in lamellar titanium aluminide, providing valuable insights for designing stronger, easy-to-manufacture alloys.

NEXT ISSUE

Here’s a sneak peek of the material covered in the next issue of A*STAR Research

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