RESEARCH
@HKUST

Creating Waves

A wave that forms part of the ocean of knowledge, a metaphor for how HKUST is part of the global community of world-class science and technology universities. The wave also represents the unceasing nature of research, with generations upon generations of intellectual minds adding to the understanding of ourselves and the world around us. Ultimately, it also symbolizes how HKUST is at the forefront of wave-making in research, innovation, and excellence.

The Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong

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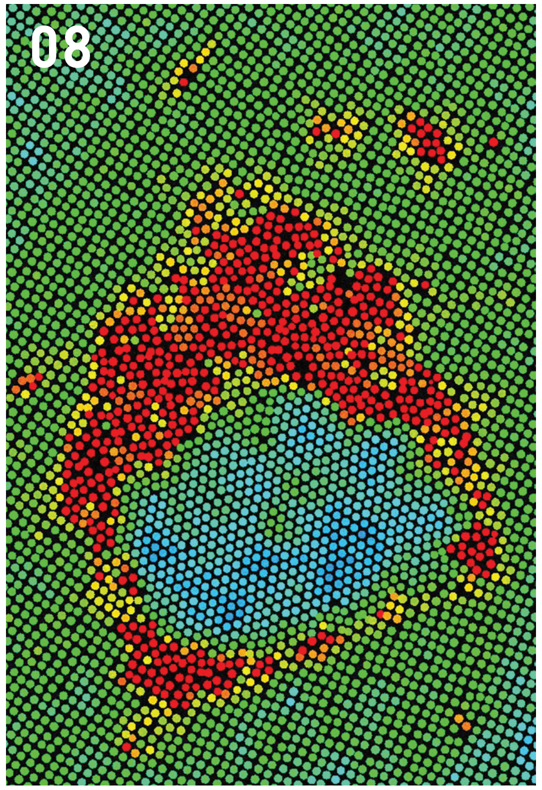
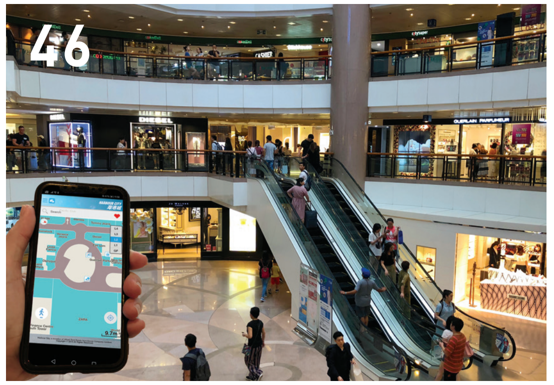
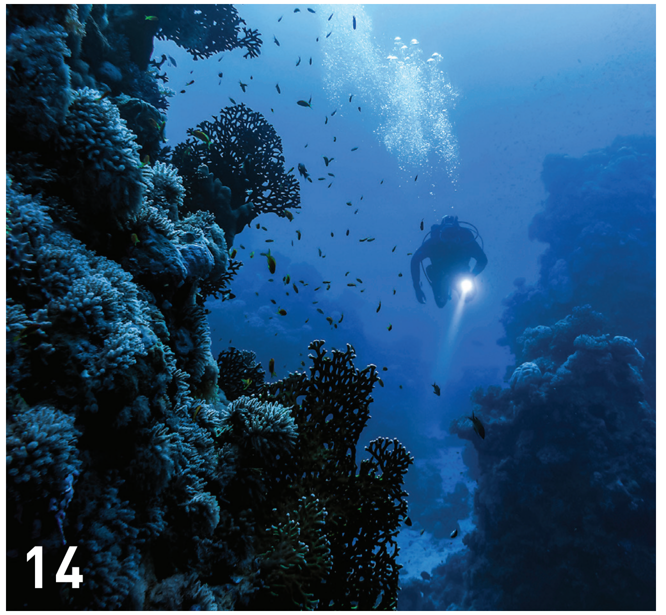






President's Foreword

Rapidly evolving technologies are opening up and shaping new directions in many aspects of our lives. I am thus very pleased to welcome you to this latest edition of *Research@HKUST*, at a time when the University is preparing for its own advance to an exciting new level as an elite research-oriented institution.

In our highly productive 28-year history, HKUST has earned a global reputation and distinctive position as an East-West science, technology, business, social science, and humanities research and education powerhouse. We are also renowned for our spirit of innovation and pioneering explorations. From the time of our establishment in 1991, we have also fostered an interdisciplinary outlook, staying committed to the crossing of frontiers and integration of fields, to drive novel discoveries and stimulate original solutions. In the same vein, we have consistently recognized and invested in world-class faculty, who form the bedrock of our institution and the core of our excellence.

I am now excited to share that we will again be taking the lead in propelling research beyond borders at our Hong Kong University of Science and Technology (Guangzhou) campus, established under a tripartite agreement signed in 2018 with the Guangzhou Municipal Government and Guangzhou University. At HKUST (GZ) in Nansha, Guangzhou, traditional departments will cease to exist, replaced instead by a multidisciplinary, theme-based, human-centered framework. Our forward-looking approach will enable us to address complex global challenges, such as sustainable development and aging populations, through an inspirational combination of knowledge breakthroughs and leading-edge solutions, integrated with the resources available in the Greater Bay Area.

With our vision, core values, as well as top faculty and students remaining at the heart of this endeavor, HKUST (GZ) will work in collaborative synergy with our founding Clear Water Bay campus, other Mainland China platforms, along with local, national, and international partners. Together, these components will help us realize our goals, take forward academia, and make global impact.

The significant contributions to the research pipeline that we currently make – from fundamental discoveries to knowledge transfer and application – are clearly on show in this issue of *Research@HKUST*. With the first phase of HKUST (GZ) campus due to be completed in 2022, we are all set to extend such endeavors well into the future.

PROF WEI SHYY
President

“
Our forward-looking approach will enable us to address complex global challenges, such as sustainable development and aging populations, through an inspirational combination of knowledge breakthroughs and leading-edge solutions, integrated with the resources available in the Greater Bay Area
”

A Word from the Vice-President for Research and Development

In this third edition of *Research@HKUST*, we continue to showcase the University's sterling contributions to breakthroughs, novel technologies, and knowledge transfer that can help to address the global challenges of our times. Such endeavors are founded on HKUST's commitment to recruiting and retaining top global minds, adopting interdisciplinary approaches, and fostering collaborations - inside and outside the University, within and beyond Hong Kong - as well as through the continuous upgrading of our leading research facilities.

Past issues of this publication have highlighted HKUST's achievements in key areas for 21st century development, including artificial intelligence, big data and analytics, neuroscience, robotics, and advanced materials, which we continue to excel at. In our latest edition, we highlight another field, among others, now set for deeper exploration with the establishment of the University's cross-disciplinary Department of Ocean Science – the first of its kind in Hong Kong.

For our curiosity-based research feature, we move to the realm of physics to investigate the thought-provoking mechanisms of melting and phase transitions. Indeed, originality, rigor and excellence are pursued across HKUST at all stages of career development. Such an approach is clearly illustrated by the discoveries of five of our trailblazing younger faculty, who are advancing deep earth insights, finding therapeutic pathways for a rare brain cancer, and exploring gender bias issues in online labor markets, among other areas.

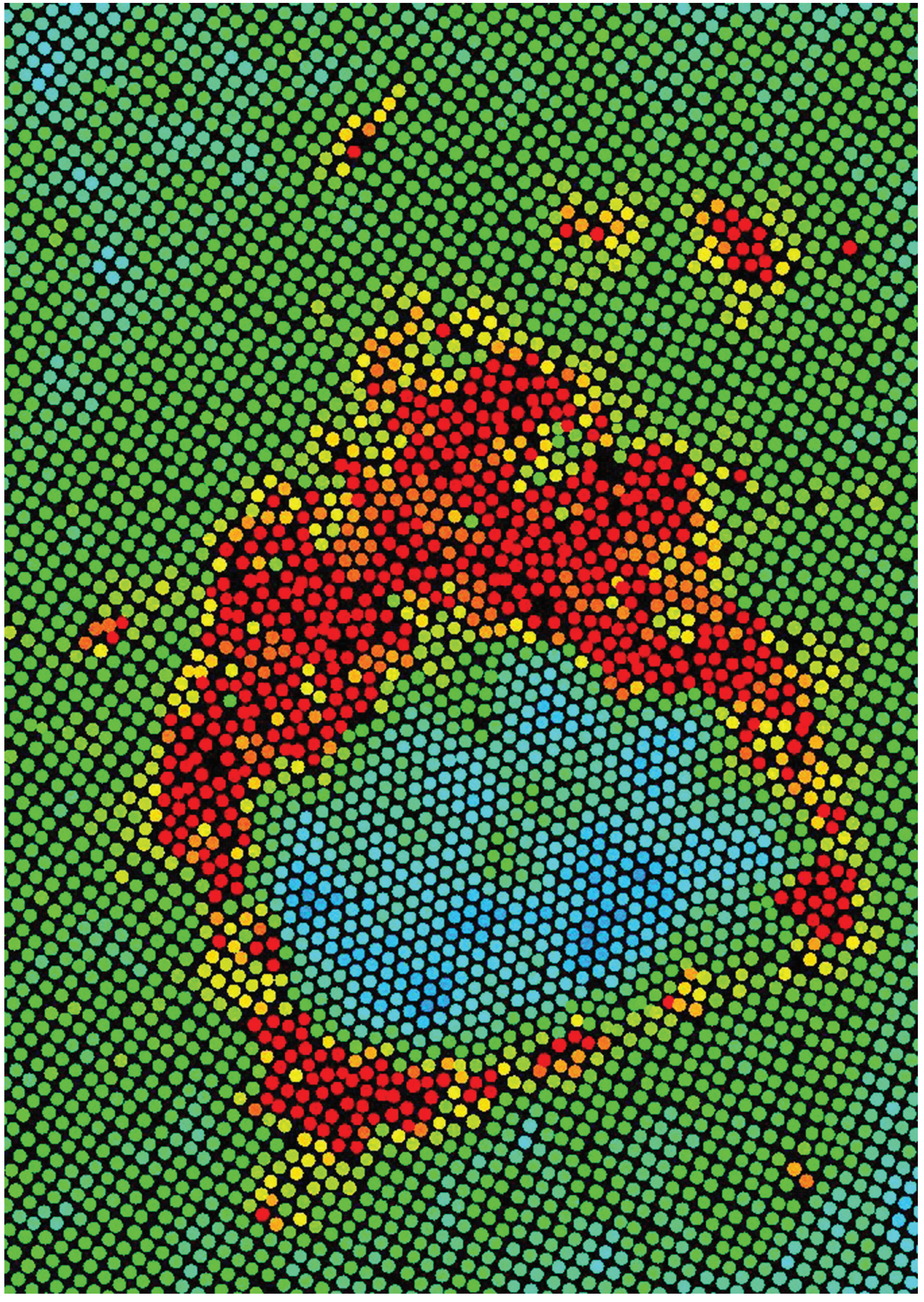
On the applied front, we look at innovations that are ushering in the era of "smart" living, such as "Internet-of-Everything" health management, monitoring individuals' exposure to air pollution, as well as enterprising technologies being transferred to the wider society, ranging from antimicrobial disinfectants to indoor location sensing.

Toward the goal to increase our social impact, we have also stepped up efforts to broaden our external partnerships with industry in fast-evolving areas, including blockchain, fintech, autonomous systems, AI and 3D visualization, aging, traditional Chinese medicine, and healthcare products. Moving forward, the University will see increased research collaboration with renowned institutions under the HK$10 billion Hong Kong government Inno@HK scheme. And when completed in 2022, our new campus in Guangzhou will be another avenue to extend our interactions in the Greater Bay Area and globally.

I hope you enjoy finding out more about the research world at HKUST and will one day come to see for yourself all the remarkable activities being undertaken here.

PROF NANCY IP
Vice-President for
Research and Development

> "To increase our social impact, we have stepped up our efforts to widen our external partnerships"



Cover feature, *Nature Materials, Vol 14*, 2015

VISUALIZING CHANGE

Diverse as they may seem, polymers, gels, liquid crystals, sand, and living cells all form part of one fascinating field – soft condensed matter, a recent interdisciplinary arrival at the cutting edge of scientific exploration spanning physics, chemical engineering, mechanical engineering, biophysics, and food science. And what might be the link between such materials? Many are disordered or partially disordered and viscoelastic – rigid like a solid over a short period of time and flow like a liquid over a long period of time. Now, researchers at HKUST are delivering fresh insights to phase transitions – when a material transitions from one form to another – while an innovative HKUST methodology, under development, is helping scientists probe further into the properties of living cells.

UNFOLDING THE MYSTERIES OF MATTER

Phase Transition Dynamics

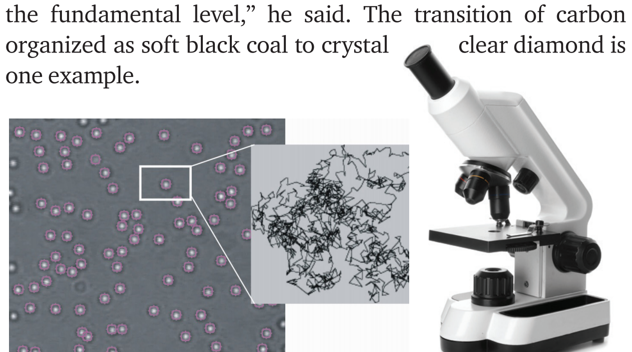
Have you ever looked at an ice cube and wondered how it melted? From the outside, or inside, or a bit of both? Or how atoms rearrange their positions to transform from graphite to diamond, both made of pure carbon but vastly different in their appearances and properties? If you have, you are considering one of the fundamental questions of physics – how matter changes from one state to another.

These questions have piqued the curiosity of soft condensed matter physicist Prof Yilong Han and his team for the past decade, with their findings attracting the attention of physicists globally. In particular, Prof Han has been intrigued by: when transition occurs; how the embryo of the new phase is formed from the parent phase; and what the microscopic kinetic pathway of a phase transition might be.

Such phenomena are "spectacularly difficult" to study, Prof Han said, because it is hard to even observe individual atoms and molecules buried inside a bulk solid or liquid, let alone track their trajectories.

"These phase transitions exist widely in nature and are important in daily life and applications. They are usually first-order transitions, which lack a theory at the fundamental level," he said. The transition of carbon organized as soft black coal to crystal clear diamond is one example.

An opal gemstone is a naturally occurring colloidal crystal. The periodicity of its crystalline lattice is comparable to the wavelength of visible light, supplying the jewel's iridescent colors. Micrometer colloidal spheres are like "big atoms", which can be used to mimic real atomic crystals.



Micrometer-sized colloidal particles dispersed in liquids can mimic large atoms and serve as powerful model systems for studying phase transitions. They have the dual advantage of being large enough to be directly observed under an optical microscope, but small enough to possess strong Brownian motion to form crystal, liquid, gas, and glassy phases. From the trajectories of particles, various physical quantities can be calculated, enabling quantitative measurement of phase transitions (*Nature Reviews Materials, 1, 15011*, 2016).

Solid-to-Solid

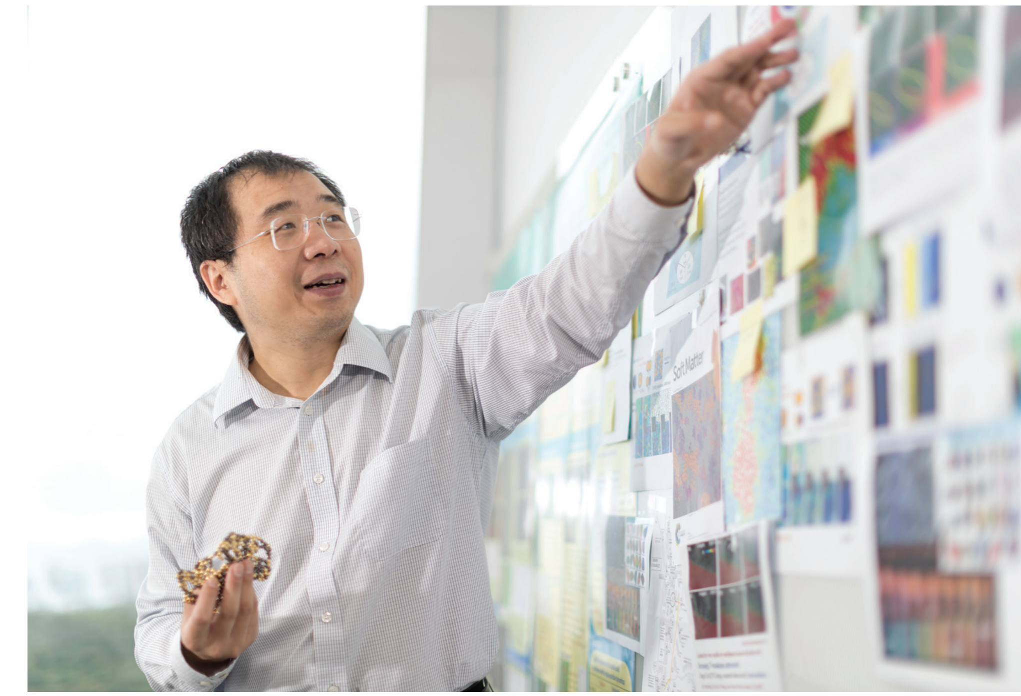
It is common for the same type of atoms to form several different crystal structures. Under specific temperature and pressure regimes, these structures can undergo phase transitions from one solid state to another. Such transitions are widely observed in metallurgy and in the earth's mantle, altering mineral properties through structural changes. While the different phases of solids have been known to exist for a long time, their kinetic pathways and the mechanisms by which they transition from one phase to another are an ongoing area of study.

Using novel diameter-tunable colloidal microspheres provided by project collaborator Prof Arjun Yodh and his group at the University of Pennsylvania, the HKUST team was able to drive phase transitions by "tuning" the particle size – that is, to tune the density or effective temperature of the system. Furthermore, the micrometer-spherical gel particles could even be visualized inside the bulk of a crystal. Thus, by beaming a heating light into the colloidal crystal, causing the contraction of microspheres, it then becomes possible to directly observe, for the first time, homogenous nucleation in solid-solid transition.

Surprisingly, the researchers found the crystal did not directly form nuclei of the final lattice structure, as conventionally expected, but liquid nuclei, which grew larger and larger, and then crystallized into the final lattice. "Such a two-step nucleation process is caused by a lower liquid-crystal interfacial energy, in comparison with crystal-crystal interfacial energy," Prof Han explained.

The novel transition pathway identified by Prof Han and his collaborators was later confirmed in metals by another research group, lending credence to colloidal systems as an apt methodology for modeling phase transitions of atomic systems. The resulting paper on solid-solid phase transition appeared on the cover of *Nature Materials, 14, 101,* 2015.

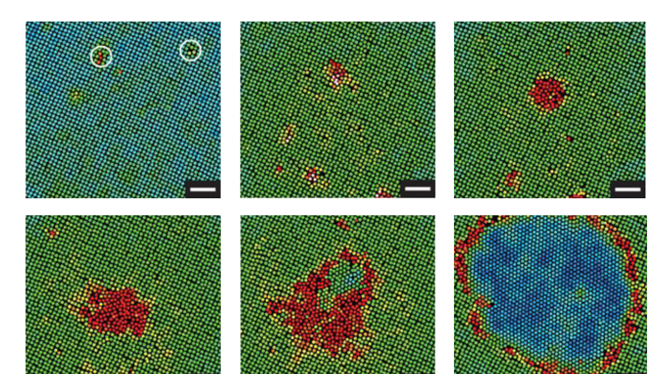
Prof Han's group further discovered that the intermediate liquid state disappears when a small amount of pressure is applied. The initial square lattice firstly generated a pair of defects called dislocations, which oscillated and triggered a few more pairs, and produced a nucleus with the final



> No one could visualize how a perfect crystal transforms into another crystal at the single-particle level in bulk before. We were the first to see the transient liquid state during such transition

PROF YILONG HAN
Professor of Physics

triangular lattice. Then, the nuclei grew by random diffusion of nearby particles. Such early-stage collective motions of particles (martensitic transformation) and the later-stage diffusive nucleation represent a novel type of transition pathway. This result and other pathways were published in *Nature Communications, 8, 14978,* 2017).



A defect-free crystal (square lattice) transforms to a new phase (triangular lattice) through the generation of nuclei with equal probability in space, otherwise known as homogenous nucleation. By directly observing the homogenous nucleation process, the research team found that the crystal does not transform to the final lattice structure as conventionally expected, but forms intermediate liquid nuclei that first grow and then crystallize into the final lattice structure in a two-step nucleation process.

Solid-to-Liquid

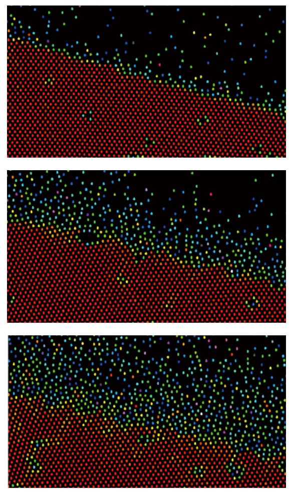
Prof Han's group has also used colloids as model systems to study crystal melting, or solid-to-liquid phase transition, achieving the first microscopic observations of surface pre-melting and internal homogenous melting.

Pre-melting

The surface of a solid often melts into a thin layer of liquid below the melting point, a phenomenon known as pre-melting. For example, two pieces of ice can fuse together below 0 °C because pre-melted surface water freezes into ice at the contact point, when not on the surface. By adding novel attractive forces between colloidal spheres, Prof Han's group was able to study pre-melting and other surface behaviors. They revealed that dimensionality is important for pre-melting, as monolayer and bilayer crystals can have distinct pre-melting behaviors. This work was published in *Nature, 531, 485,* 2016. Surface pre-melting is important in skating, glacial movement, and snowflake formation.

Melting from Within

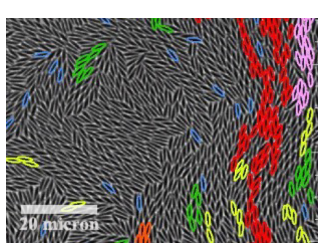
Prof Han's group also realized melting from within a defect-free crystal. In doing so, they found the transition process was initiated via particle swapping, where several adjacent particles switched places in a looping motion before baby liquid nuclei were formed. This contrasted with normal melting, triggered by the formation of crystalline defects. The findings appeared in *Science, 338, 87,* 2012.



The colloidal crystal provides a single-particle resolution for surface pre-melting. The crystal dissociates from the solid part to become liquid.

Liquid-to-Glass

In contrast to the well-understood crystal, disordered glass is poorly comprehended, with the nature of glass transition ranked as one of the 125 major scientific open questions by *Science*. Take, for example, a supercooled liquid frozen to a glass. While its structure hardly alters, why does its dynamics slow down about 10 - 15 times (viscosity increases by 10 - 15 times)? Are there little-known structural changes responsible for this? Seeking the correlation between structure and dynamics is a major area of endeavor in the search for greater knowledge of glass.



Fast-moving particles are shown in color, demonstrating dynamic heterogeneity (non-uniform dynamics)

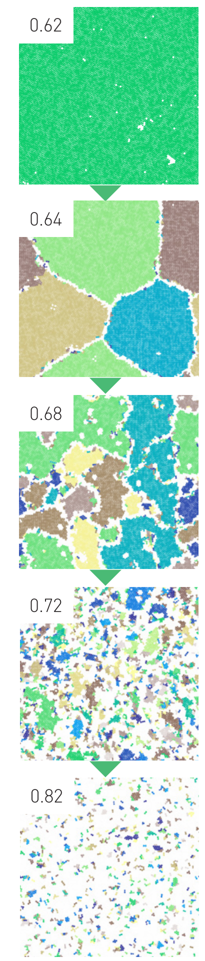
Prof Han's group got off to an early start on this, performing the first experiment on colloidal glass composed of non-spherical particles and discovering a novel glass transition for anisotropic particles, whereby rotational motion jams into the glass first, and translational motion jams into the glass afterward, increasing the density (*Phys. Rev. Lett. 107, 065702,* 2011). In addition, they found various structure-dynamics correlations *(Nature Communications, 5, 3829,* 2014*)*.

Prof Han's group produced colloidal glass by vapor deposition, and explored glass behaviors near the glass-vapor interface with single-particle dynamics for the first time. They resolved different types of collective motions of particles near the surface, reflecting two surface layers *(Nature Communications 8, 362,* 2017*)*.

Crystal-to-Glass

Most crystals, such as metals, are polycrystals composed of billions of randomly-oriented crystalline grains. Each grain is a small single crystal, made up of billions of atoms or molecules on a periodic lattice. If the typical grain size is reduced to just a few atoms, the polycrystal will become an amorphous solid, i.e. glass. How, then, would one distinguish ultrafine-grained polycrystals from glass? Is it just a matter of terminology? Surprisingly, these questions have rarely been asked.

Prof Han's and his group ventured into unexplored scientific territory by being the first to answer this basic question – ultrafine-grained polycrystals are notoriously difficult to fabricate due to their instability, and as a result, have rarely been studied. They compressed crystals into polycrstyals, and further into glass, using simple models by simulations. Their findings revealed that there is, indeed, a point of differentiation between fine-grained polycrystals and glass – at a surprisingly large grain diameter of around 15 particles. Many physical quantities feature a signature sharp polycrystal-glass transition at this size, as opposed to a continuous crossover. These behaviors were shown to be robust in different models in 2D and 3D. It also provides a novel angle to study glass formation from a crystal, instead of the conventional and well-studied process of forming glass by quenching a supercooled liquid. This work was published in *Physical Review X, 8, 041023*, 2018.



Polycrystal or Glass?
A single crystal at area fraction 0.62 is compressed to polycrystals (0.64, 0.68) and then to glass (0.72,0.82). White regions show disorder.

Prof Han, who joined HKUST in 2007 after completing his doctorate and post-doctoral research at the University of Chicago and University of Pennsylvania respectively, has been fascinated by the beauty of physics since his high school days in Mainland China. He is driven to solve basic problems, first and foremost out of deep interest and curiosity. That his work is providing insights, which could assist in the development of new materials and optimization of existing ones, adds a further exciting order of magnitude to the matter.

Prof Han received the International Organization of Chinese Physicists and Astronomers Achievement in Asia Award (2014) and the Chinese Young Scientist Award (2016), for his research contribution to the understanding of phase transitions.

THE PHYSICS OF LIVING MATTER

DNA, proteins, lipids, as well as living cells and tissues, are other forms of soft matter. Understanding the mechanics and physical properties of these squishy materials adds further insights into the physics of living matter.

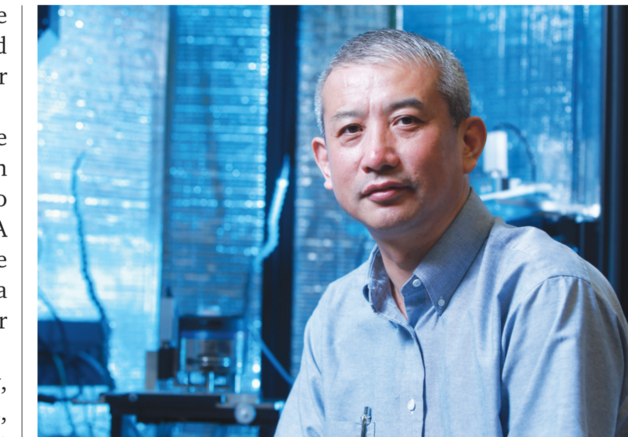
However, living cells are not only delicate, but their Jello-like consistency also poses a major challenge for researchers. Touch the cell with a probe and an adhesive force is generated, due to the cell's "stickiness", leading to inaccurate measurements. A cell's elasticity is also not constant (imagine trying to measure the "hardness" of a drop of liquid). Innovation is, therefore, a must to find methods to map cellular properties without either destroying the cell or making contact with it.

This is the quest of experimental physicist Prof Penger Tong, who works at the interdisciplinary interface between physics, biology, and chemistry. Prof Tong and his collaborators have set out to overcome both of these difficulties by developing a novel way to measure viscoelasticity and other mechanical properties of living cells, by engineering a new type of atomic force microscope (AFM) probe that operates in air rather than liquid.

To create the probe, they glued a tiny glass fiber needle – approximately one micrometer in diameter and 100 micrometers in length – to an AFM cantilever. The needle was covered with a special coating that prevented proteins from sticking to the probe. Then, with the needle tip placed a few nanometers above the cell surface, the tool was pressed to the living cell, creating a contactless method of measuring mechanical properties of a cell while allowing its integrity and activities to remain undisturbed. "Everything is in the air except the tip, which is placed in a thin liquid layer above the cell's surface," Prof Tong explained.

> "I want to understand the mechanical properties of cells and the physics of living matter"
>
> **PROF PENGER TONG**
> Chair Professor and Head, Department of Physics

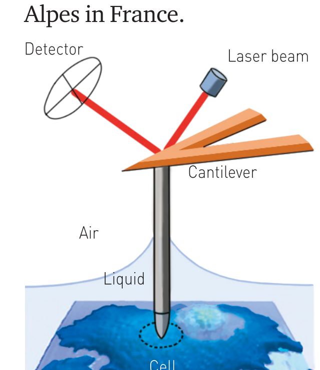
The team worked experimentally on refining the accuracy of the device, alongside working out the hydrodynamic theory needed for the AFM setup in collaboration with theoretical physicist Prof Elisabeth Charlaix at the Université Grenoble Alpes in France.

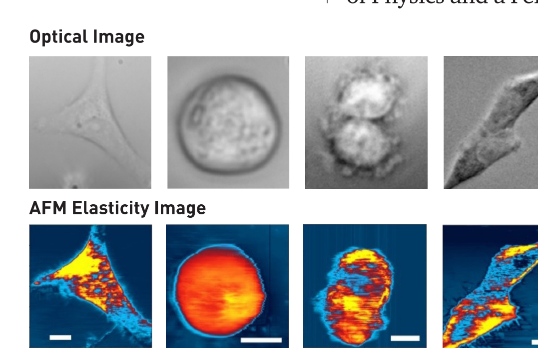


Using the newly-engineered AFM probe, they measured the mechanical properties of HeLa cells, epithelial cysts, neurons, and postsynaptic density droplets in collaboration with HKUST's Division of Life Science faculty, including Prof Robert Qi, Prof Pingbo Huang, and Prof Mingjie Zhang. Comparisons were made to assess whether the cells had distinct functions, or were healthy or diseased, providing new knowledge related to the roles played by the cell's volumetric and elastic properties.

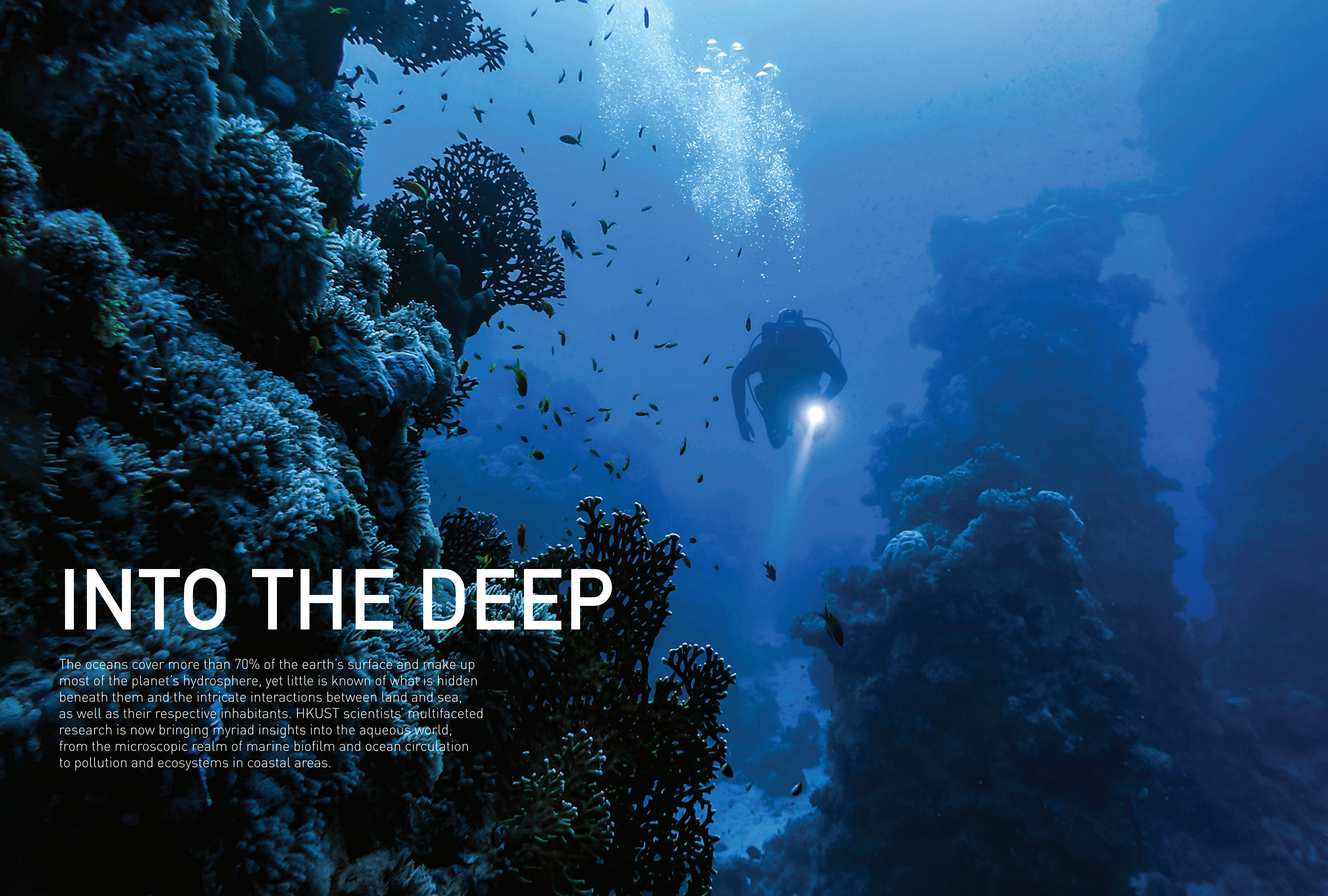
"The hard thing in biology is you have large cell-to-cell variations," Prof Tong noted. "But, that is what life is," he added. "Cellular diversity is tremendous, between different types of cells and within the same kind of cells, even though they are made of similar molecular building blocks." Prof Tong and his team remain undaunted by the demanding task of systematically quantifying and theorizing these many variations. Indeed, in advancing their biological physics research, they hope to uncover the mechanobiological differences between healthy and cancerous cells. They would also like to explore the differences between living and dead cells, an endeavor that would take them to a truly amazing frontier of science – the interface of life and death.

Prof Tong is Head and Chair Professor of the Department of Physics and a Fellow of the American Physical Society.





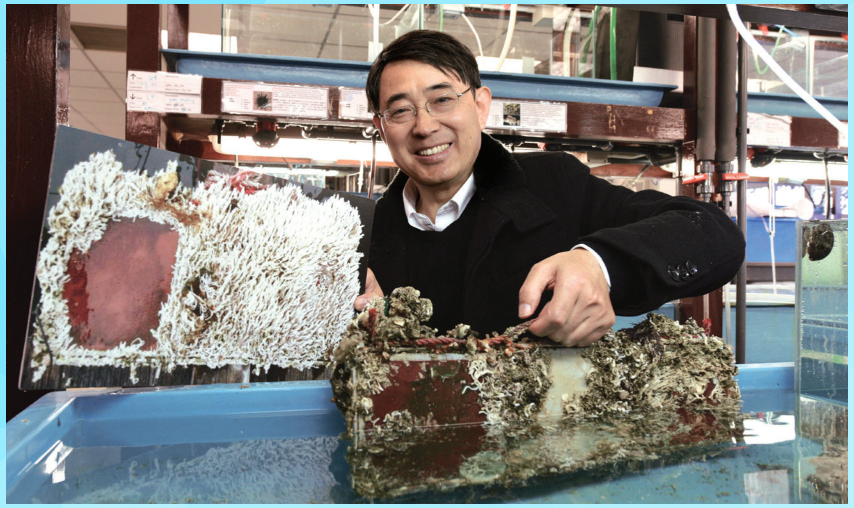
Elasticity of a Dividing HeLa Cell
A long needle AFM probe is lowered toward the upper surface of a live HeLa cell in water and set for vibration in two frequencies to measure the cell's height and mechanical response, respectively. Water flowing between the needle tip and cell surface cannot keep up with the fast vibrations, creating a drum-like effect that causes cell deformation. Measuring the force required to deform the cell surface, locally, provides the elasticity map. Yellow/red/blue show areas of high/medium/low stiffness, respectively (Reprinted with permission from *Guan et al., Phys. Rev. Applied, 8, 044010,* 2017).



INTO THE DEEP

The oceans cover more than 70% of the earth's surface and make up most of the planet's hydrosphere, yet little is known of what is hidden beneath them and the intricate interactions between land and sea, as well as their respective inhabitants. HKUST scientists' multifaceted research is now bringing myriad insights into the aqueous world, from the microscopic realm of marine biofilm and ocean circulation to pollution and ecosystems in coastal areas.

SIGNALING BREAKTHROUGHS



> The intricate relationships between microbes, animals, and the environment, whether in the ocean or on land, are treasure troves of secrets waiting to be discovered

PROF PEIYUAN QIAN
David von Hansemann Professor of Science,
Head, Department of Ocean Science

The equilibrium of any ecosystem is established by three components that exert influence on each other – the environment, microbes, and animals. Chemical signals provide communication between the three, playing a crucial role in the composition and overall functioning of the ecosystem.

Marine biologist Prof Peiyuan Qian uses modern bioinformatics and unique sequencing methodologies in his quest to understand the delicate interactions between microbe populations, animals, the environment, and the chemical cues that tie them together. It is a research journey that has taken him from coastal marine environments to the deepest depths of the ocean, and finally, to life on land.

Biofilm Discoveries

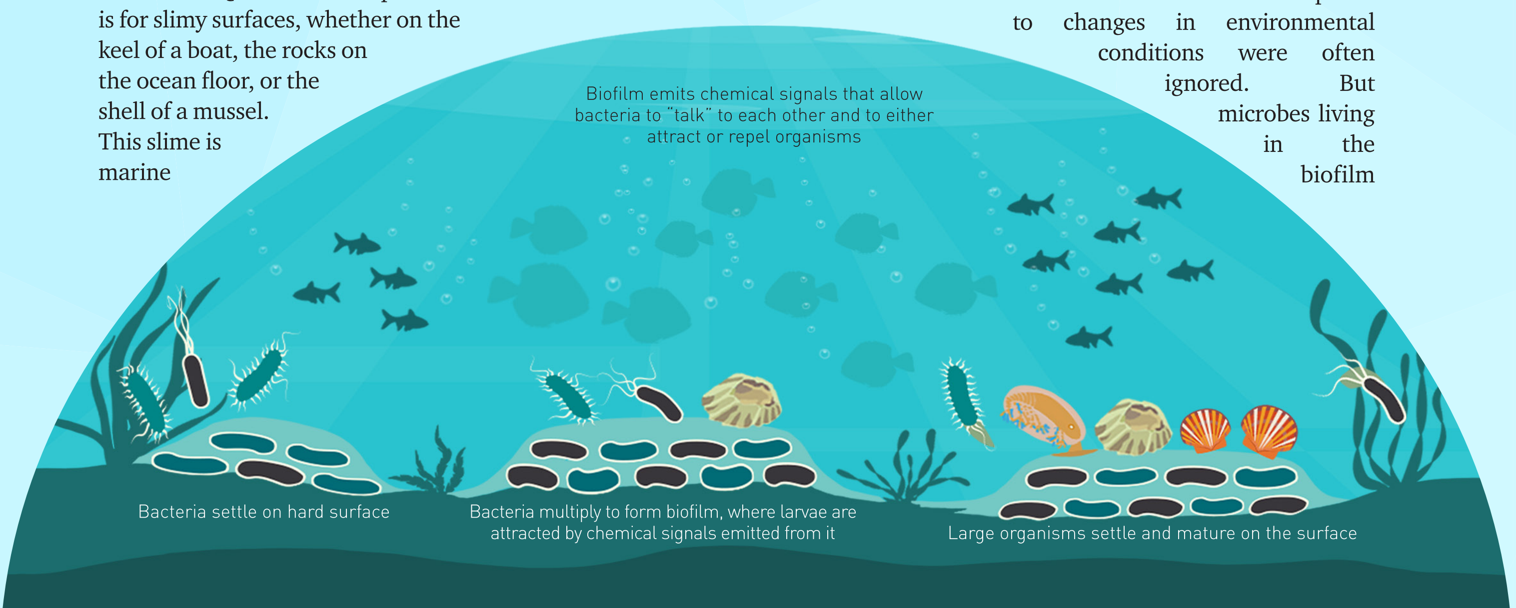
One of Prof Qian's scientific passions is for slimy surfaces, whether on the keel of a boat, the rocks on the ocean floor, or the shell of a mussel. This slime is marine biofilm, housing thousands of types of bacteria, algae and other micro-organisms that emit chemical signals which affect the behavior of larger macro-benthic organisms.

These benthic invertebrates are aquatic organisms that settle in or on the seafloor, such as shellfish, molluscs, crustaceans, and barnacles. Although their movement is limited, they are still mobile in their larval stages and respond to chemical signals emitted from biofilm. Through this exchange of signals, these benthic organisms determine where they will eventually settle and live.

Prof Qian, David von Hansemann Professor of Science and Head of HKUST's newly established Department of Ocean Science, has been the first globally to study the dynamics of marine biofilm and the chemical interactions within it. His lab is unique in its focus on larvae, biofilms, and chemical cues that affect the behavior of marine animals, and how the biofilm structure is affected by environmental changes. Among their findings is the discovery that certain non-toxic organic compounds, synthesized by bacteria themselves, can either attract or repel benthos to encourage or discourage settlement.

Such new knowledge is based on advances in big data mining and high-throughput sequencing technology that Prof Qian applied to single genes, genomes, and metagenomes. "Without sequencing technology, you are not going to be able to recognize the high biodiversity and various functions of microbes living in the biofilm," he said.

"In the past, people took a snapshot approach. In taking samples and analyzing them, rapid changes of both microbial community structures and functions in biofilm in response to changes in environmental conditions were often ignored. But microbes living in the biofilm are very sensitive to environmental changes, such as water temperature and nutrients. What you see today is different from what you see tomorrow."



Heavy fouling on boat surfaces

Antifouling solution applied on ship surfaces to repel marine benthos

Prof Qian uses a novel and comprehensive methodology, where sample analysis incorporates analysis of environmental variables.

By applying this understanding, Prof Qian's lab has been able to identify butenolides, simple non-toxic organic compounds produced by bacteria that can repel benthos and can be synthesized. He then extended his findings further to develop environmentally friendly antifouling coatings using butenolides as repellants to prevent marine foulers from attaching to the hulls of boats, solving a major problem in the shipping industry where settlement of unwanted organisms or seaweed on boat surfaces costs billions of dollars annually.

"We need to find broad-spectrum compounds that work in a wide range of conditions," he said. Conventional chemical coatings aimed at discouraging the fouling process are typically toxic or damaging to the surrounding environment and, as a result, have been banned.

Following tests on marine and fresh-water fish, 13 of Prof Qian's antifouling compounds have been patented and several are now being trialed on specialized vessels in Chinese waters. Meanwhile, aquaculture farmers want to know the type of biofilm that can attract the larvae of benthic species, such as abalone and oysters. Such use of compounds derived from biofilm is just one of many potential gifts from marine slime.

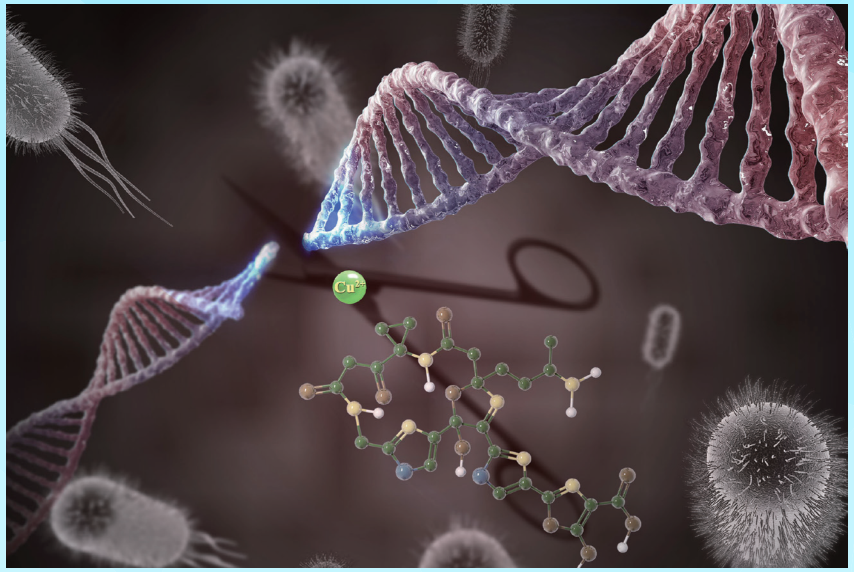
Racing to Beat Antibiotic Resistance

The basic principle of microbes in the biofilm emitting signals that attract or repel other organisms has huge implications beyond the sea, including biomedical research into new cancer treatments, antibiotics, and understanding of antibiotic resistance.

To assist with this, Prof Qian has used genome mining and synthetic biology to screen compounds found in biofilm. He has sped up such work substantially by conducting systematic analysis of gene clusters in microbial genomes rather than the conventional method of screening for bioactives, which is slow and less effective. Novel biosynthesis pathways can then be identified, and potential bioactive compounds predicted, based on the analysis of gene arrangements of biosynthesis pathway gene clusters.

It takes a computer cluster about a month to identify some of the novel pathways from over 12,000 microbial genomes, based on the algorithms and matrix created by his team. "After we discovered a new biosynthesis pathway, we used our cloning platform to clone the entire biosynthesis pathway gene cluster in one go into yeast or *E. coli*, or another microbial host, and then used them as "factories" to produce the novel compound. Furthermore, we conduct gene editing to knock out or knock in genes to improve the production of such compounds," Prof Qian explained. "It is now possible to produce the compound biologically by understanding the genome."

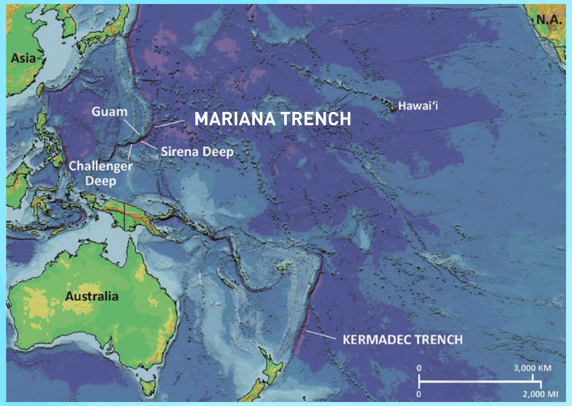
A recent and much-publicized Qian discovery is how bacteria can mutate to develop enzymes that can break down antibiotics, leading to antibiotic resistance (*Nature Chemical Biology*, 2018).



E. coli produces colibactin, activated by copper, and can cause double-stranded DNA breakage, which leads to cancer

Peptide antibiotics, such as polymyxin, vancomycin, and teixobactin, are among the last-line-of-defense antibiotics for broad-spectrum bacteria. By analyzing nearly 6,000 bacterial genomes through a network-associated global genome-mining approach, and chemical and enzyme validation, a family of D-stereospecific resistance peptidases (DRPs) was found to be responsible for peptide antibiotic resistance. Prof Qian and his team also discovered that many strains of bacteria have developed these resistant enzymes.

The researchers are now contributing to the global search for novel classes of antibiotics. In a paper published in *Nature Communications* in 2018, they analyzed over 7,000 bacterial genomes, and identified two new compounds, brevicidine and laterocidine, that demonstrated efficacy against pathogens such as *E. coli* in a



Studying how deep-sea crustaceans and mussels have adapted to living and thriving in the Mariana Trench's extreme conditions

mouse model with low risk of resistance. Prof Qian believes many more peptide antibiotics with low risk of resistance are still to be identified.

Using the same research strategy (microbiome analysis, genome mining, gene cluster cloning, and gene editing, bioactive compound screening and structure identification of novel compounds), his collaborative team successfully isolated and identified the chemical structure of colibactin from human gut bacteria *E. coli*, and decoded the mystery of how colibactin causes DNA damage, leading to human colon cancer (*Nature Chemical Biology*, 2016; *Nature Chemistry*, 2019).

Prof Qian received a State Natural Science Award from China's State Council in 2016.

Deep Ocean Survival Tactics

Prof Peiyuan Qian's interest in biofilm has extended to a depth of 11,000 meters in the Mariana Trench. In this work, he examined how crustaceans have adapted to such an inhospitable environment and its huge hydrostatic pressures and sometimes toxic conditions, involving high concentrations of hydrogen sulfate and methane gas. He found the answer lies in the chemical compounds these creatures produced to make their surfaces more fluid and tolerant of such conditions (*Molecular Ecology*, 2017). Prof Qian used bioinformatics to sequence the genome of deep-sea vent mussels and compared the results to their shallow-water counterparts to try to ascertain how they have adapted. He found that the symbiotic relationship between microbes in the gills of deep-sea mussels was responsible for transporting toxic chemicals outside their gill epithelial cells. Changes in their genetic makeup were also found, involving enzymes and enhanced immune systems (*Nature Ecology and Evolution*, 2017).

Amphipod from Challenger Deep, Mariana Trench - about 7.5cm long, 7 times longer than shallow-water amphipods

Shallow-water amphipod - about 1cm long

PROVINCIAL MARINE LAB HOSTED AT HKUST

HKUST now hosts the Hong Kong Branch of the Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou) to support the development of marine science and technology in the Greater Bay Area. Headed by Prof Peiyuan Qian, the Lab's 15-year vision includes research on Greater Bay Area marine ecosystems that are under stress from climate change and pollution. It will also develop key interdisciplinary research and technologies for strategic resource utilization in the South China Sea, expand areas for marine industry advancement, and help promote a high-quality marine economy in Guangdong.

DIAGNOSIS AND PROGNOSIS OF OCEANS

> Through our mathematical modeling, we can extrapolate limited spatiotemporal field data and predict the future of the oceans

PROF JIANPING GAN
Chair Professor of Ocean Science and Mathematics

Rivers, deltas, sea shelves, and the deep ocean basin to which they are connected form an amazing interlinked ecosystem, influenced by human activity but shaped by the underlying physical and biogeochemical processes of nature – wind, tides, currents, temperature, biogeochemical substances, climate change, and the cycle and web of life itself.

This watery world is the domain of physical oceanographer Prof Jianping Gan, who brought the study and mathematical modeling of complex ocean dynamics to Hong Kong when he arrived at HKUST 16 years ago. Since then, research based on numerous seagoing adventures and related modeling studies has provided new understanding of the patterns of ocean circulation and ecosystems in coastal waters and in the broad South China Sea basin, with important global significance for water management, pollution mitigation, and climate change.

Ocean Circulation

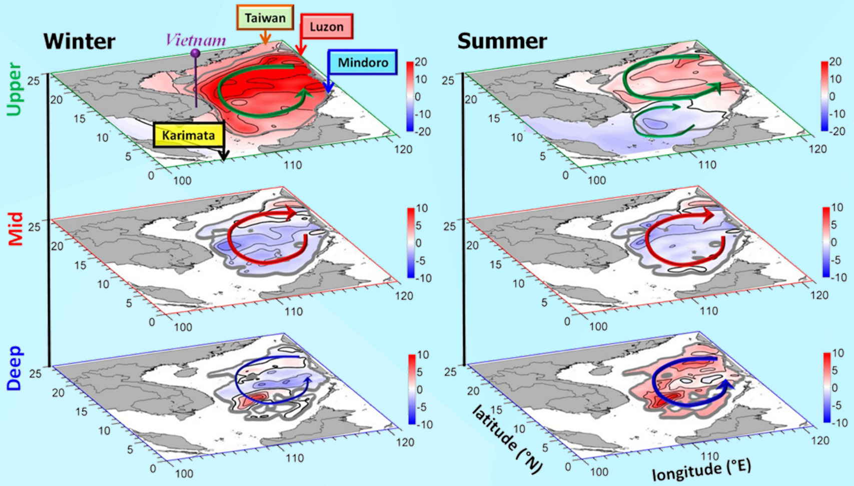
In his research, Prof Gan uses a unique combination of geophysical fluid dynamics, numerical modeling, coupled physical-biogeochemical dynamics capabilities, and field measurements. From data collected on survey expeditions around Hong Kong, the Pearl River Delta estuary, South China Sea, and adjacent western Pacific Ocean, Prof Gan identified the three-layer alternating spinning circulation of the South China Sea, which provided an important hydrodynamic framework for understanding heat and energy transport, the carbon cycle, ecosystems, and climate variability in the region. His research elucidated physically for the first time that waters in the region circulated anti-clockwise at the upper layer, clockwise at the mid-layer, and anti-clockwise in the deep layer. The resulting article, published by the *Journal of Physical Oceanography* in 2016, attracted global attention, becoming one of the most downloaded papers during the year.

The dynamics that Prof Gan observed is crucial for determining the transport of water masses, energy, and biogeochemical substances in the region and adjacent western Pacific. Such implications have contributed to an understanding of the generation of tropical cyclones and storm surges, sustainability of fisheries, and the progress of climate change. They can also lead to more accurate forecasting and mitigating action.

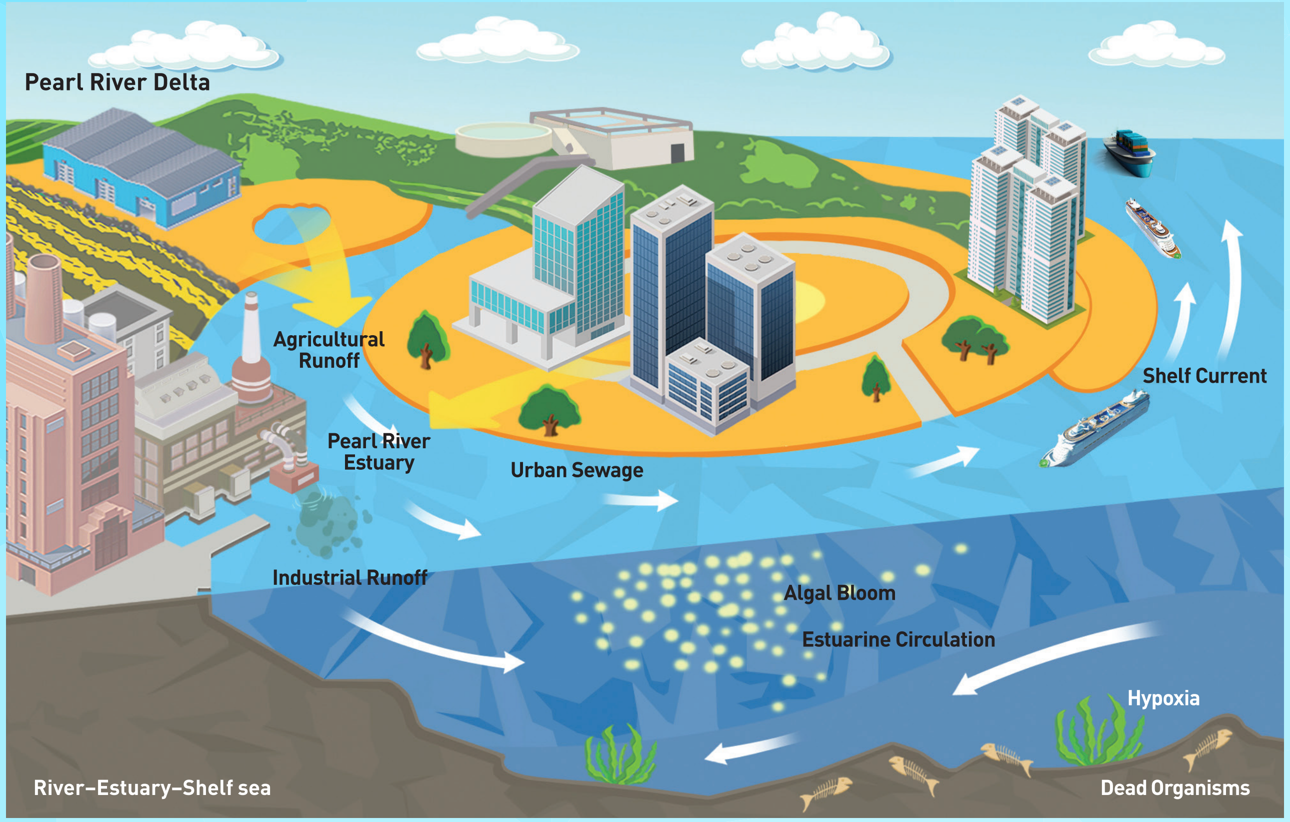
Tracing Hypoxia and Eutrophication

Building on such understanding, Prof Gan is now setting out to add insights toward two major local problems of international interest: hypoxia and eutrophication. Hypoxia is manifested in what are known as "dead zones" in oceans, seas, rivers, and lakes – when oxygen saturation falls below 2mg per liter and life can no longer be sustained. After dead organisms sink to the bottom

THREE-LAYER CIRCULATION



A vertically alternating anti-clockwise, clockwise and anti-clockwise three-layer circulation was identified in the South China Sea by a large-scale mathematical model. The three-layer circulation shapes the three-dimensional pattern of water motion from season to season in the South China Sea, and plays a critical role in transporting heat and energy that affect regional climate variability and biogeochemical substances in sustaining biological productivity (*J. Phys. Oceanogr.*, 46, 2309, 2016).



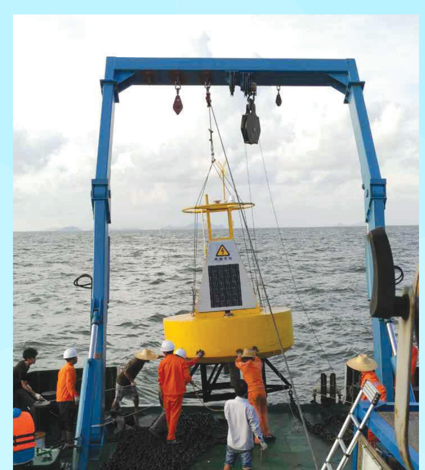
Agricultural and industrial runoff as well as urban sewage contain nutrients such as phosphates and nitrates that are carried from rivers by ocean currents, which then pass through the Pearl River Delta estuary. These nutrients form eutrophication and algal blooms on the surface and hypoxia (low oxygen) at the bottom over the continental shelf off Hong Kong.

of the ocean, their decomposition consumes more oxygen and contributes to hypoxia. It is closely linked to eutrophication, caused by excessive nutrients discharged into the ocean by river and sewage effluent, that results in algal blooms.

"Hong Kong is surrounded by ocean and its oceanic area (3,000 km²) is twice as big as its terrestrial area and facing great challenges," Prof Gan said. "It has a problem with eutrophication – which we see in red tides – and it is getting worse. Hypoxia will likely spread across Hong Kong waters, according to current trends, if we do nothing."

Pinpointing the precise sources of eutrophication and hypoxia through evidence-based strategies is the way forward to assist future water management schemes and rectify the problem. Prof Gan and his collaborators are now participating in the large-scale theme-based research project Ocean Circulation, Ecosystem and Hypoxia around Hong Kong Waters, known as OCEAN-HK and funded by Hong Kong's Research Grants Council. Comprising leading marine researchers from Hong Kong and Mainland China, the five-year project launched in 2017 straddles disciplines such as physical, chemical and biological oceanography, and marine ecology. The investigation of the waters in and near Hong Kong, the Pearl River Delta, and the Greater Bay Area of the South China Sea is based on extensive multidisciplinary field surveys, real-time monitoring, and the novel coupled physical-biogeochemical pollution modeling system. Prof Gan, the OCEAN-HK coordinator and co-principal investigator, explained that this holistic approach combines field observations of hydrographic properties, ocean currents, nutrients, oxygen, plankton, and pollution, with atmospheric and physical modeling of circulation and tides, and biochemical modeling of the ecosystem.

The HKUST team includes biological oceanographer Prof Hongbin Liu, who is investigating food web dynamics; and marine ecologist Prof Stanley Lau, for his expertise in identifying and tracing strains of bacteria. The three researchers are among the key members of the University's new Department of Ocean Science, which will spearhead research and teaching in the field, inspire future generations of oceanographers, and is



Deployment of buoy for an ocean survey conducted by joint shipboard mapping

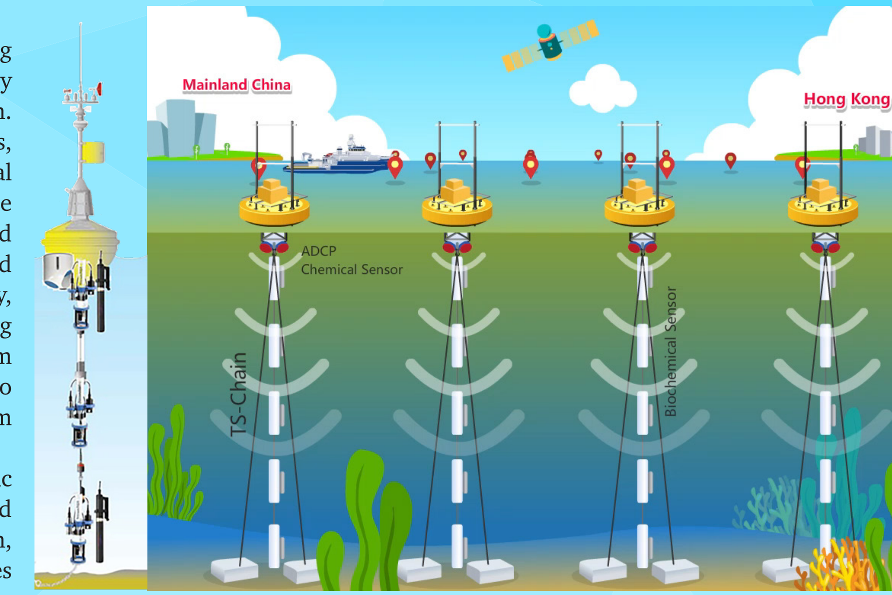
the first of its kind in Hong Kong.

Data is being gathered continuously, and in real time, using a network of mapping by research vessels, and time-series monitoring by buoys and unmanned autonomous research vessels. A particular area of concern is the city's iconic Victoria Harbor that is currently experiencing a trend of decreasing dissolved oxygen at the bottom depths of the water, despite major government clean-up efforts.

Real-time Data Collection

The research will inform the Hong Kong government's future strategy for water treatment and protection. Key government departments, including the Environmental Protection Department, the Agriculture, Fisheries and Conservation Department, and the Hong Kong Observatory, are involved through a steering committee, and benefiting from training that will enable them to run their own monitoring system developed by the project.

Although the team's dynamic model for the diagnosis and prognosis of eutrophication, hypoxia, and their consequences for the ecosystem will be unique to the Pearl River Delta area, it will also be relevant to the studies of hundreds of other coastal water systems. "It provides many innovative methodologies and approaches that are new and applicable to other hypoxic zones in the world," Prof Gan said. "It is creating holistic understanding of eutrophication and hypoxia in river-estuary-ocean shelf systems both locally and globally."



Moored buoys in the waters off Hong Kong. Real-time physical and biogeochemical data are transmitted to a land-based station and integrated into a mathematical model for forecasting. The buoys sense salinity, temperature, pressure, dissolved oxygen, chlorophyll, nitrate, and atmospheric variables.

Among the project's different aspects is the monitoring of water temperature. Prof Gan predicts that, if current human activity is not modified, within 100 years, temperatures may rise by 3 to 4 °C, which will increase the partial pressure of carbon dioxide (pCO_2) in the ocean and change the mitigating effect the ocean has on atmospheric carbon dioxide (CO_2). "I don't know if the problems facing our oceans can really be addressed by ocean science alone, given the complexity involving science, social, economic, and political issues. But I am sure that without ocean science, we can't resolve them," he said.

Prof Gan, who conducted his early research at the Ocean University of China and Third Institute of Oceanography, followed by postgraduate work in Canada and the US, has been one of the most active sea-going researchers in the region, venturing as far as the Antarctic in the 1990s. He still actively takes to the ocean for fieldwork surveys.

CENTRE FOR OCEAN RESEARCH IN HONG KONG AND MACAU

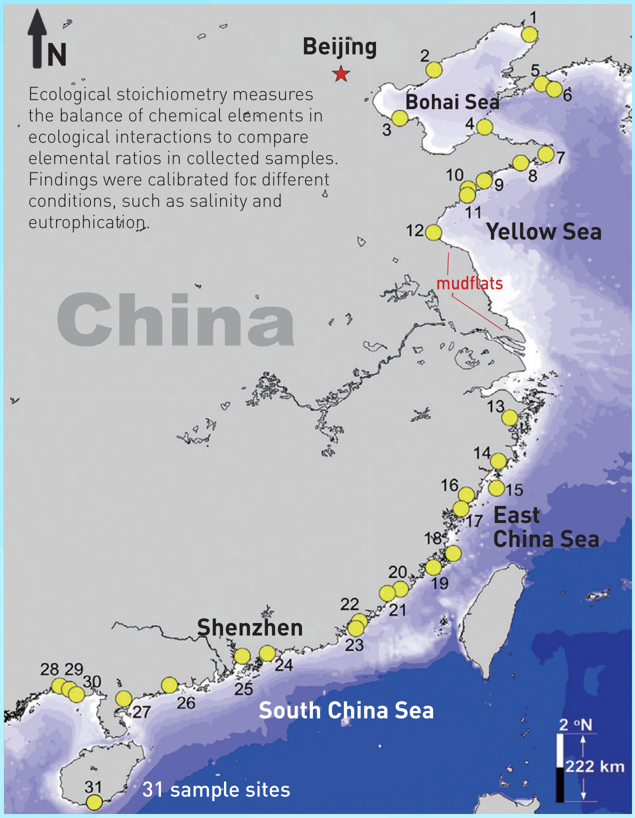
The recently established Centre for Ocean Research (CORE) in Hong Kong and Macau at HKUST serves as a platform for integrated and interdisciplinary ocean science research. It focuses on four key areas: air-sea-land interactions, ocean physics and biogeochemistry, environmental simulations and forecasting, and ocean big data. Exploration of these areas will provide strategies to address regional challenges in marine sustainability, with potential global implications. CORE is headed by Prof Jianping Gan, participated by members from universities in Hong Kong and Macau, and supported by the Qingdao National Laboratory for Marine Science and Technology. CORE is expected to make significant contributions toward the development of ocean science and technology in the region.

WHY DELTA OYSTERS ARE BLUE

Metal contaminants flowing into rivers and seas from ever-increasing industry along the 14,500-kilometer China coast is not good news for oysters and other marine creatures – or for lovers of seafood. Now, after mapping the entire coast for metal pollution for the first time, HKUST researchers have identified the most toxic sites.

Prior to this, the northern coast was regarded as the most polluted, due to heavy industry in the area. But marine scientist Prof Wenxiong Wang and his team found that the Pearl River Delta estuary suffers a problem more severe.

The discovery was made when the researchers analyzed over 3,000 individual oysters, mussels, and clam samples, gathered within a short time frame from more than 30 stations along China's coastline.



Environmental Pollution, 224, 658 (2017)

Building on earlier monitoring in the delta, the full coastal mapping revealed oysters in the South and East China Seas accumulated higher concentrations of cadmium, zinc, and copper, compared with those in the Bohai Sea and Yellow Sea; and significantly higher concentrations of nickel and chromium at levels several times higher than food safety limits. Prof Wang's long-term research in the delta also found while the levels of metals such as nickel and chromium have declined, others, such as copper and zinc, have increased.

There are government regulations for emissions of the most toxic metals, for example, lead and mercury. This is not the case for minerals essential for humans, such as copper and zinc, which are also toxic in excessive quantities.

Prof Wang and his team use radioisotopes to trace metal behavior in organisms. The radioisotope quantifies the rates of metal contamination and where it goes in the cellular structure and organs, while the kinetics governs the rate of metal accumulation and removal. It is the excessive copper that gives contaminated oysters their alarming blue hue.

His latest work demonstrated that oysters can act as a sentinel organism for tracking the source of zinc contaminants in marine environments. Such scientific monitoring provides vital information for industry planning, control, and clean-up operations. In the June 2019 edition of the prestigious journal *Environmental Science & Technology*, Prof Wang's publication was selected as the cover feature.

While metal pollution levels in our waters appear to have improved due to changes in industry, that does not mean the problem is solved. "There is a lesson from Hong Kong. In the 1970s, it was very polluted, but now the environment is better because the industry has moved. But we are paying a big price for the past, because of the contaminated sediment. Even though pollution in the water is reduced, at the bottom it is still there, and needs to be cleaned up," he said.

"We now have a better understanding of the metal pollution distribution along the China coastal area"

PROF WENXIONG WANG
Chair Professor of Ocean Science

Oysters severely contaminated with copper have a blue hue

NEXT-GENERATION
TRAILBLAZERS

Five young faculty with the vision to transform our understanding of the world

DEEP EARTH REVELATIONS

HKUST deep earth discoveries have thrown fresh light on how the extremely high temperatures and pressures at work in our planet's mantle may alter fundamental assumptions of how carbon, the building block of life, operates many kilometers beneath our feet. The findings by Prof Ding Pan, a cross-disciplinary expert in physics and chemistry, have contributed to a new understanding of the deep carbon cycle, which in turn could provide further insights into carbon-related hot topics, ranging from diamond formation to controversial proposals on inorganic petroleum formation.

Prof Pan used quantum mechanics simulations to determine, for the first time, the dielectric constant of water in the upper mantle. Having gauged this basic property governing the solvation of water, significant water and carbon interactions and reactions could then be explored, for example, the amount of carbon that can be stored and transported at such depths.

These measurements were previously not possible to accurately ascertain, given the challenges of simulating the mantle's extreme environment experimentally. In utilizing quantum mechanics, Prof Pan was able to calculate forces applied to atomic-level interactions, which could then be scaled up. To do so, he used one of the world's largest parallel supercomputers, Tianhe-2, housed in the National Supercomputer Center in Guangzhou as well as high-performance clusters at HKUST.

Prof Pan went on to reveal that carbon in the water-rich fluids, or geofluids, in the upper mantle transports carbon primarily as highly active ions rather than carbon dioxide, as previously thought. The finding enhances the possibility of carbon species reacting with other minerals, such as silicates and iron.

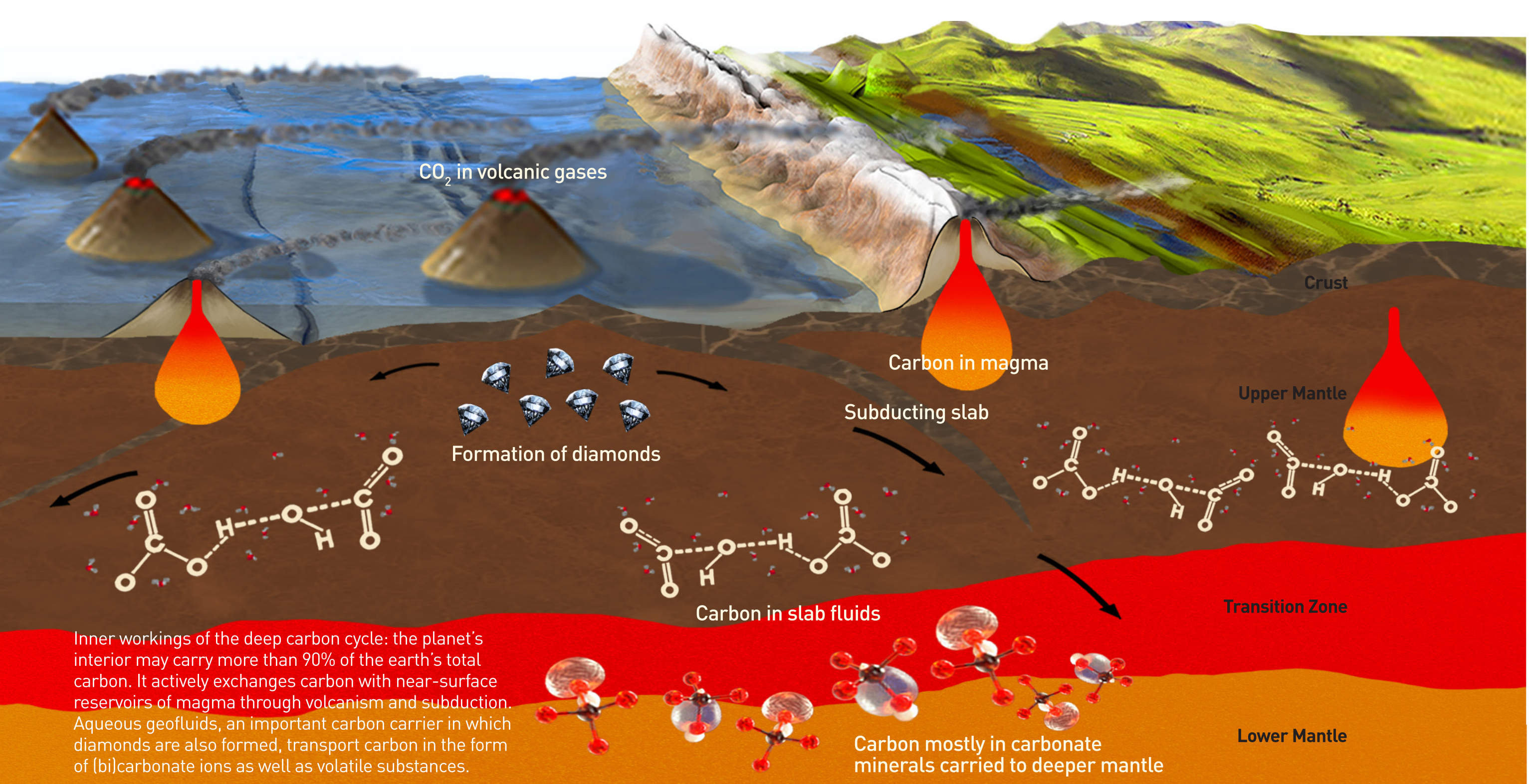
In 2018, the young scientist was awarded a prestigious Croucher Innovation Award. He is using the funding it provides over five years to develop novel theoretical tools, such as Raman and infrared spectroscopy using first-principles molecular dynamics.

With these tools, he aims to provide an atomic picture of how carbon takes its diamond form, and contribute to the highly debated hypothesis of abiogenic petroleum formation during the carbon cycle, as opposed to fossil fuels being solely derived from ancient organic materials.

On the macro level, he hopes to answer challenging questions on carbon transportation inside the earth, energy implications of the carbon cycle, and carbon's role in the beginning of life. Working in affiliation with the HKUST Energy Institute, he will also assist research into sustainable e-fuel energy storage.

> "Now we can use the fundamental laws of physics to help us understand carbon in the deep earth"
>
> **PROF DING PAN**
> Assistant Professor of Physics and Chemistry

Prof Pan's quantum mechanics simulations have been developed in collaboration with fellow researchers in the Deep Carbon Observatory (DCO), a leading international collaboration involving over 1,000 scientists. He is the only member from Hong Kong and was awarded a 2019 DCO Emerging Leader Award.



Inner workings of the deep carbon cycle: the planet's interior may carry more than 90% of the earth's total carbon. It actively exchanges carbon with near-surface reservoirs of magma through volcanism and subduction. Aqueous geofluids, an important carbon carrier in which diamonds are also formed, transport carbon in the form of (bi)carbonate ions as well as volatile substances.

THE SECRETS OF MICRORNA BIOGENESIS

Human cells have more than 2,000 microRNAs (miRNAs), tiny structures playing critical roles in the regulation of gene expression, and a greater understanding of their functions holds clues for future control of many medical conditions, from infections to cancers and neurodegeneration.

miRNAs affect numerous biological processes, such as cell death, stem cell differentiation, and metabolism, among others. They can also be significant actors in human diseases, if their expression level in cells is not kept under strict control, with miRNA biogenesis among the most important regulatory mechanisms, according to biochemist Prof Tuan Anh Nguyen. The different factors involved in biogenesis, the process of miRNA synthesis, are the focus for Prof Nguyen's lab at HKUST.

Such exploration is built on numerous studies, including Prof Nguyen's, investigating the role of the human Microprocessor protein complex, which is responsible for the maturation of miRNAs. His past research has contributed to elucidating the cleaving mechanism initiating miRNA production and also overturned previous theories on the composition of the Microprocessor. These discoveries served as the basis for a 2018 Croucher Innovation Award.

Prof Nguyen's research adopted a combination of challenging methodologies involving the purification of protein components in the Microprocessor and, for the first time, observation of its biochemical activity when mixed in an assay of RNA. Bioinformatics and single-molecule technology were used to affirm the results, analyzing the behavior of the Microprocessor with different RNA precursors. X-ray crystallography helped identify the structure of the proteins, reinforcing initial findings.

Given the numerous types of miRNA precursors (pri-miRNAs), Prof Nguyen believes that the complex requires the collaboration of many more proteins and other factors. The recent work from his group at HKUST has discovered that heme, a critical small molecule playing an important role in oxygen transfer in human blood, along with SRSF3, an RNA

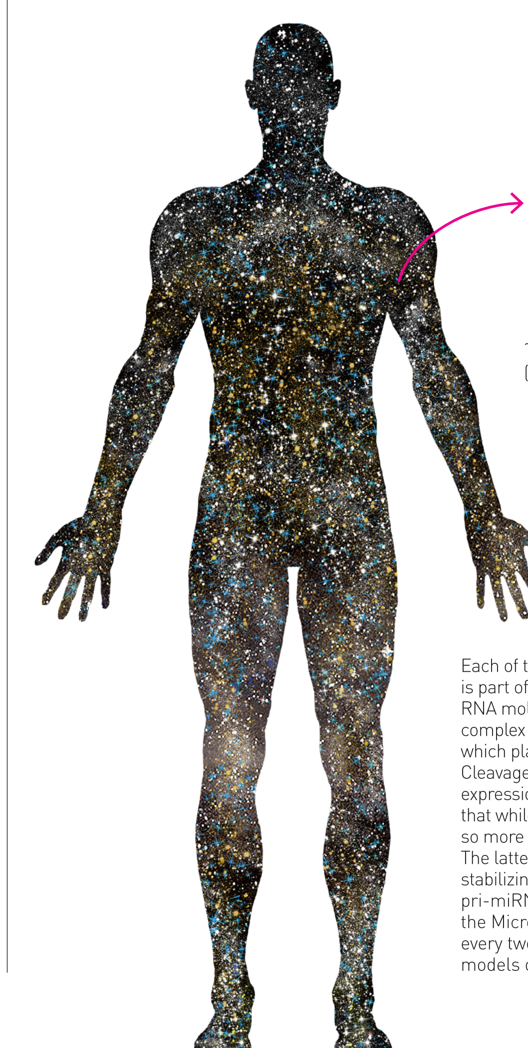
> "We can now study RNA-interacting enzymes in a high throughput manner, allowing us to understand enzyme functions and characteristics rapidly"
>
> **PROF TUAN ANH NGUYEN**
> Assistant Professor of Life Science

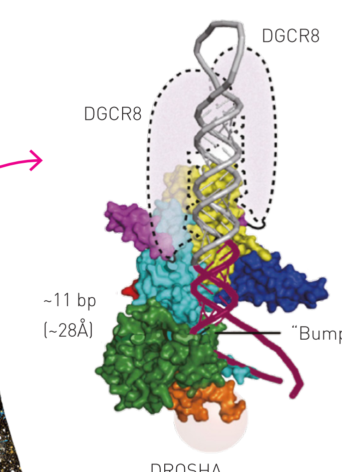
splicing factor, is responsible for orienting the Microprocessor on pri-miRNAs to the precise position for cleaving.

Prof Nguyen will use his five-year Croucher funding to investigate links between human RNA-binding proteins (RBPs) and miRNA production. His group is integrating core biochemistry and bioinformatics to investigate the enzymology and functions of RBPs. Previous enzymology research methods were limited to studying one enzyme with one or several substrates at a time. "Now we can work with thousands of substrates," he said. This work has implications for controlling diseases such as Severe Acute Respiratory Syndrome (SARS) and HIV.

Prof Nguyen joined HKUST in 2017 after completing his PhD at the Korea Advanced Institute of Science and Technology (KAIST) and his postdoctoral fellowship at Seoul National University. He received the Young Scientist Award from the Korean Society for Structural Biology in 2015.

In the longer term, the rising star's dream is to build a set of human RBPs for use in drug screening.





Each of the 2,000 plus miRNAs in a human cell is part of more than 1,000 full-length precursor RNA molecules (pri-miRNAs). The Microprocessor complex comprises DROSHA and cofactor DGCR8, which play key roles in the cleaving of pri-miRNAs. Cleavage has a major influence on miRNA expression levels. Prof Nguyen's research revealed that while DROSHA alone can do the job, it does so more accurately in combination with DGCR8. The latter plays multiple roles by binding and stabilizing DROSHA, and accurately interacting with pri-miRNAs. His research further elucidated that the Microprocessor comprises one DROSHA to every two DGCR8 molecules, contrary to previous models of a 1:4 or 1:6 ratio (*Cell*, 2015 and 2016).

HARNESSING EVOLUTIONARY INSIGHTS TO PREDICT TREATMENT OUTCOMES

Despite decades of research, the prevention and effective treatment for many forms of cancer remain elusive to scientists. Now, the pairing of big data and cancer genomics is deepening understanding of the evolutionary history of tumors, opening up improved forecasting of the course of the disease in individual patients and greater potential for optimized therapeutic options, rather than the current one-size-fits-all approach.

The computational models of mathematician and bioinformatics specialist Prof Jiguang Wang and his lab are at the forefront of such advances in precision medicine. A combination of human algorithmic ingenuity, big data, and genome sequencing has located genetic markers that help to trace cancer tumor evolution. Then, by comparing findings across a growing database of genomic information, case histories and treatments, past treatments that have proven successful can serve as a model for existing patients with similar cancer genome markers.

"We think of the cancer system as dynamic, not static, using mathematical methods to study the past to predict the future," Prof Wang said. Wang Lab members regularly handle 200-400 terabytes of data, made accessible through projects such as The Cancer Genome Atlas.

> "What fuels me to work harder is the idea that we can provide some hope in often hopeless situations"

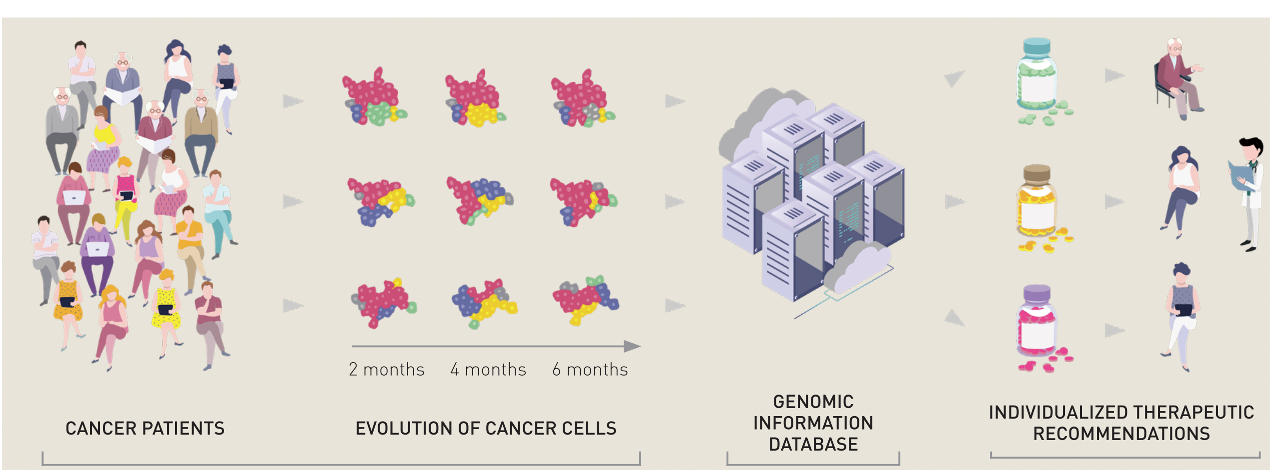
PROF JIGUANG WANG
Assistant Professor of Life Science and Chemical and Biological Engineering

The novel analytical approach allows researchers to longitudinally map changes in the mutations of a single tumor across many points of time and to integrate this with cross-sectional analysis of tumors from many different patients, using statistical models to indicate the relationships of cancer-driving gene mutations and the order in which they usually occur (*eLife,* 2014). Prof Wang is now adopting the method to glioblastoma, a particularly aggressive and invariably fatal brain cancer, as well as using a similar strategy for pan-cancer analytics.

In collaboration with Columbia University, Samsung Medical Center, and other institutes, Prof Wang and co-researchers identified a highly branched evolutionary pattern for the disease under therapy (*Nature Genetics,* 2016 and 2017). They found mutations in the initial tumor might not be present in relapsed tumors, suggesting clones discovered after treatment had diverged ahead of diagnosis. Indeed, researchers estimated they may have been in existence as early as 10 years before the cancer was first discovered.

Working with Samsung Medical Center and Beijing Neurosurgical Institute, Prof Wang also revealed significant amplification of several proto-oncogene proteins present in glioblastomas, with a positive response observed after using targeted inhibitors (*Nature Genetics,* 2018; *Cell,* 2018). Finally, targeting truncal rather than branch alteration, which might lead to repopulation of non-targeted branches, was more effective in preventing tumor reoccurrence.

The interdisciplinary Wang Lab is now working closely with leading front-line oncologists, particularly in Asia, to apply this knowledge. An artificial intelligence system is being trained to correlate drug response and genomic data. It is hoped that the system can automatically predict the optimal drug for different patients.



Cancer patients' clinical records, biomedical images, blood, tumor tissues, and genomic information are captured over time in a database. A combination of algorithms, big data, machine learning, and genome sequencing are applied to patients' genomic information, to reveal patterns, causal relationships, and clinical biomarkers from these multimodal data. HKUST is developing an AI system to correlate drug response and genomic data for prediction of optimal therapies. If a "twin" case is matched in the huge database and the treatment successful, this can be used to predict the optimal drug for current patients with similar cancer genome markers.

EXPLORING GENDER PREFERENCES IN ONLINE LABOR MARKETS

All else being equal, a female applicant has

13%

higher odds of being hired than a male applicant

The rapid growth of online labor platforms, such as Upwork, Freelancer, and Zhubajie, allows millions of workers to perform a range of administrative tasks, design and web programming work without geographical and temporal constraints. Many organizations are now using the online workforce as a convenient and cost-effective way to meet business needs.

In the first academic study of its kind, Prof Jing Wang and her co-author examined gender hiring bias in the online labor market and found evidence of a preference in favor of female workers. While gender inequality has been a long-standing issue in labor economics, Prof Wang's findings stand in stark contrast to the majority of traditional labor market research that has revealed discriminatory behaviors against females.

The study used a conditional logistics econometric model to analyze a dataset of 264,875 job postings and 5.7 million job applications from a leading online labor platform. Findings showed that the odds of a female applicant being hired were 13% higher than that of a male applicant, after controlling for observable worker attributes. "The platform does not collect gender information, but we were able to infer workers' gender from their names and profile photos by utilizing machine learning techniques," she said.

Prof Wang also introduced a quasi-experimental technique to address endogeneity issues by identifying workers with names that are unlikely to reveal their gender and contrasting the likelihood of workers being hired before and after they posted a profile photo. "Females with uncommon names enjoyed a 17% increase in the odds of being hired after posting a profile photo, compared with only 5% for males, suggesting that revealing their gender gives a disproportionate advantage to females," she noted.

To identify the mechanism underlying the female hiring preference, Prof Wang conducted a further experiment via Amazon Mechanical Turk. This showed female-associated traits such as trustworthiness and cooperativeness help overcome the uncertainty and opportunism of online marketplaces. She also observed that female hiring bias diminishes as employers gain more experience with online labor platforms; and such bias stems solely from consideration of applicants from developing countries, not developed ones.

"As online labor marketplaces continue to grow in size and reach, it is imperative for policymakers to establish guidelines and regulations to promote equality in labor participation and generate socially efficient hiring outcomes," Prof Wang said. She suggested that platform owners should allow workers to use pseudonyms

> "We are the first to look at this gender bias in online markets and I am fascinated to see a positive hiring bias in favor of female workers"

PROF JING WANG
Assistant Professor of Information Systems, Business Statistics and Operations Management

or avatars on their public-facing worker profiles. "Workers, especially males, could add information to their profiles to signal trustworthiness and cooperativeness. Female workers should upload their photos to maximize their gender advantage," she said.

The novel approaches that Prof Wang developed for this research called on her distinctive background of having earned a first degree in computer science and doctoral studies in management information systems. She has published articles in *Management Science, Information Systems Research, Proceedings of the National Academy of Sciences (PNAS),* and *Data Mining and Knowledge Discovery.*

LINKING POLICY, PM_{10} AND LIFE EXPECTANCY

We may not actually see the danger, except in extreme cases. But World Health Organization (WHO) estimates indicate over 90% of people worldwide are living in areas that do not meet WHO air quality guidelines for particulate matter (PM) levels, which are known to have serious health impacts, including higher risks of stroke, lung cancer, and heart disease.

Bringing the health costs of these hazards into clearer focus, research by environmental economist Prof Guojun He and his collaborators has shown that sustained exposure to air pollution significantly lowers people's life expectancy, a question that previously remained unanswered.

To do this, Prof He's research used a natural experiment created by a winter heating policy in Mainland China. The decades-long policy provided free or greatly subsidized coal north of the Huai River but not to the south. With the north burning large amounts of coal for heating, it significantly increased PM_{10} (particulate matter 10 micrometers or less in diameter) levels. Compiling the most comprehensive dataset yet on health and pollution in a developing country, Prof He found particulate pollution to be 46% higher just north of the river, leading to a reduced average life expectancy of 3.1 years. The estimates also implied that more than 3.7 billion life-years could be saved if all of China complied with its own Class 1 standards for PM_{10}.

His findings have since been used to develop an online Air Quality Life Index™, which quantifies the number of years that air pollution shaves off life-spans in different countries.

Prof He and his collaborators also studied the contemporaneous effects of China's temporary emissions ban to improve Beijing's air quality ahead of and during the 2008 Olympic Games. Using data from 34 major Chinese cities between 2006-2010 (before, during, and after the Games), Prof He found that monthly PM_{10} decreased by an average of 18% in 2008 and 30% during the Games in Beijing and other affected cities. This dramatic improvement in air quality led to a substantial decrease in cardiovascular and respiratory deaths. Prof He estimated that a 10% drop in PM_{10} equated to an 8% decline in monthly all-cause mortality rates, representing more than 285,000 premature deaths averted annually.

Prof He was selected to join the World Economic Forum's Young Scientists Class of 2018 and his work has won multiple awards, including Best Paper from China Health Policy and Management Society (2016) and two Gregory Chow Best Papers (2015, 2018) from the Chinese Economists Society.

CHINA'S WINTER HEATING POLICY LINE

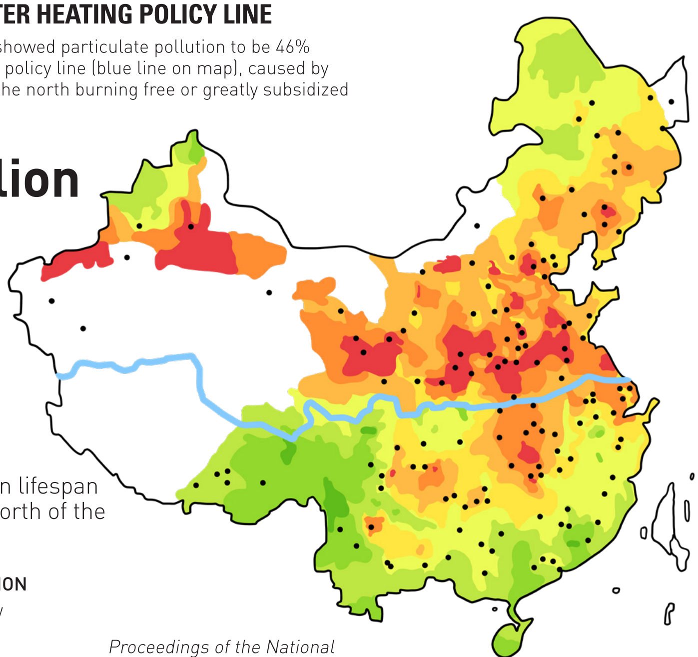
The HKUST study showed particulate pollution to be 46% higher north of the policy line (blue line on map), caused by residents living in the north burning free or greatly subsidized coal as winter fuel.

3.7 billion

life-years saved if all of China complied with its own Class 1 standards for PM_{10}

3.1

years shorter in lifespan for residents north of the policy line



PM CONCENTRATION
- Relatively Low
- Moderate
- High

Proceedings of the National Academy of Sciences, 114, 39 (2017)

BEIJING OLYMPICS
(IMPROVED AIR QUALITY)

8%

decline in monthly mortality for every 10% drop in PM_{10}

> When you witness a transition in public awareness, you do feel you could be contributing

PROF GUOJUN HE
Assistant Professor of Social Science, Environment and Sustainability, and Economics

SMART LIVING

Next-generation mobile networks, or 5G, are set to transform the future. But in what ways will this versatile world of faster and more reliable mobile communications actually reshape people's lives? Scientists and engineers at HKUST are at the forefront of such pivotal change, with a range of advanced technologies under development that seek to utilize the 5G wireless platform to empower individuals' patterns of life. Get ready to explore novel devices for personal health monitoring, your own air pollution avoidance strategies, as well as responsive energy-saving building controls and materials. Step into the smart life.

PERSONAL HEALTH MANAGEMENT

Healthier Options

The era of connectivity being ushered in by 5G is often referred to as the "Internet-of-Things" (IoT), where billions of tiny sensing devices are embedded in everyday gadgets and devices, interconnected via a wireless infrastructure that enables ubiquitous sensing and communication. However, it is more the "Internet-of-Everything" that will characterize the digital landscape, from the perspective of computer science engineer Prof Qian Zhang and her researchers.

The HKUST team's goal is to bring the benefits of such development down to the individual level, particularly to curb unhealthy lifestyle behaviors early and to boost the prevention of chronic diseases. Conditions such as diabetes, heart disease, cancer, and stroke are forecast by the World Health Organization to rise to 73% of all deaths by 2020 and comprise 60% of the global burden of disease.

Prof Zhang, a specialist in mobile and spectrum management of wireless networks and mobile communications, and her team are seeking a holistic approach to reduce those estimates. They aim to do so by looking at ways of understanding people's current levels of health and making the relevant data accessible to encourage personal lifestyle adjustments. This involves the design of novel sensing applications, embedding artificial intelligence and data analytics built on superfast connectivity in devices that can monitor, log, recognize, and analyze patterns with little inconvenience to the user; and the provision of such information to healthcare providers, who recommend or deliver targeted strategies.

> The Internet-of-Everything helps us to monitor, analyze, and adjust our daily behaviors for smarter and healthier living

PROF QIAN ZHANG
Tencent Professor of Engineering,
Chair Professor of Computer Science and Engineering

As a result, the team has developed intriguing monitoring devices, including a special pillow to record changing sleep patterns, wearables such as glasses, and other smart contactless devices that can measure how and what we eat, to raise awareness and try to prevent health conditions from arising in the first place.

Sleeping

The Zhang team has designed a smartphone-based auto-adjustable pillow system that detects, monitors, and treats the nighttime breathing difficulty known as sleep apnea. The system can assess whether the data collected by the wearable device actually represents a person experiencing sleep apnea or is simply a result of "signal noise". Conventional diagnosis requires a user to attend a sleep center and does not include treatment.

Using a blood oxygen sensor and novel algorithms, the sleep apnea event can be detected wirelessly in real time, and the height and shape of the pillow automatically adjusted. Through continuous monitoring of blood oxygen levels, the data collected and analyzed by the system can evaluate the pillow adjustment and select a suitable position. In trials on 40 patients, the portable and cost-effective system reduced the duration and number of sleep apnea events by more than 50%. The HKUST team was among the first to propose and implement such a combined detection, monitoring, and treatment device for sleep apnea. The technology has now been patented and certified by the then-China Food and Drug Administration (now renamed as the National Medical Products Administration) after collaborations and clinical trials with Shenzhen People's Hospital.

Eating

Moving on from sleep, Prof Zhang and her team started to explore novel routes for diet monitoring – another vital aspect of personal health management and disease prevention. The conventional method to track diet is to manually keep a log, which requires discipline on the part of the subject. Wireless-enabled diet-monitoring spectacles, devised by Prof Zhang, meant this process could be automated by placing an electromyography sensor into the temple of the eyeglasses to measure movement of the temporalis muscle used for chewing. The prototype comprised a sensor, microcontroller SD shield/card, and Bluetooth radio. Working together with a smartphone, the spectacles achieved up to 96% accuracy for counting the number of chewing cycles and up to 90.8% accuracy for classifying five food types, including potato chips, crackers, and corn *(IEEE Internet of Things Journal*, 2017*)*.

However, as wearables still require the individual to make a conscious effort, Prof Zhang sought to advance this "on-body" technology to an "off-body" solution. The result was Smart-U utensils, designed to unobtrusively recognize the contents of a meal while it is being eaten.

Employing spectroscopy as the underlying principle, the prototype utensil uses an array of sequentially-modulated LEDs as light sources to capture the spectra reflected by the foodstuff. By combining the wavelengths and intensities of the reflected light, both determined by the composition of the food, the prototype utensil could then analyze and recognize 20 types of food, including pork, beef, and carrot with 93% accuracy; while a prototype glass could recognize six types of drinks. Potential uses include tracking food intake and providing personalized food suggestions based on prior consumption and recommended nutrients *(IEEE INFOCOM*, 2018*)*.

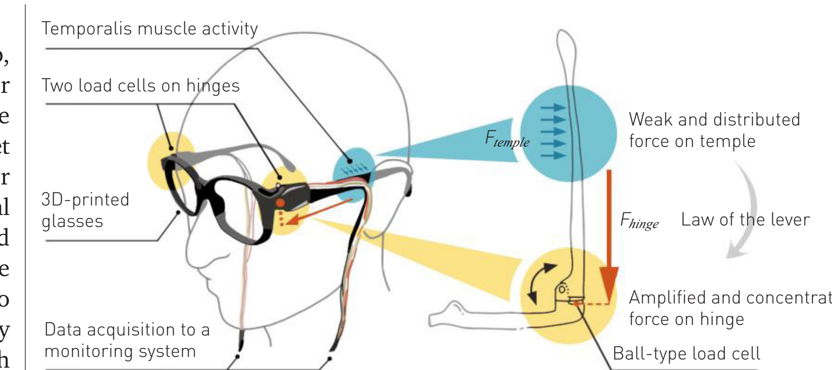


Fig. 1 Sensors installed in smart glasses measure chewing cycles to determine intake schedule and amount, as well as the force of chewing to distinguish between five types of food with up to 96% and 90.8% accuracy, respectively

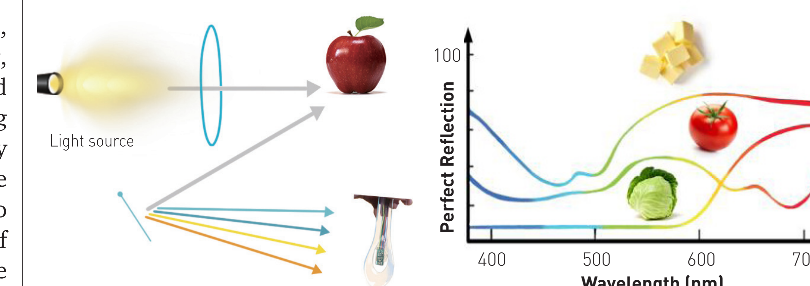
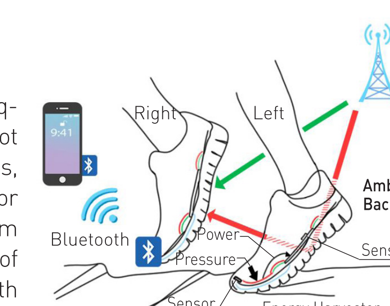


Fig. 2 3D-printed smart utensils with LEDs shine light onto food. A diffraction gradient separates the wavelengths of reflected light, while the chemical composition of the food dictates the percentage of the light reflected. The specialized machine-learning algorithm analyzes the combination of both values to detect 20 types of food and six types of drinks with 93% accuracy. Data is transmitted to a smartphone for further processing via Bluetooth.

Prof Zhang is the recipient of a 2017 Natural Sciences for Research Excellence Award (First Class) from the Chinese Institute of Electronics, 2012 Ho Leung Ho Lee Foundation Science and Technology Innovation Award, and 2012 China Young Scientist Award. She is also a Fellow of IEEE and holds more than 50 patents.

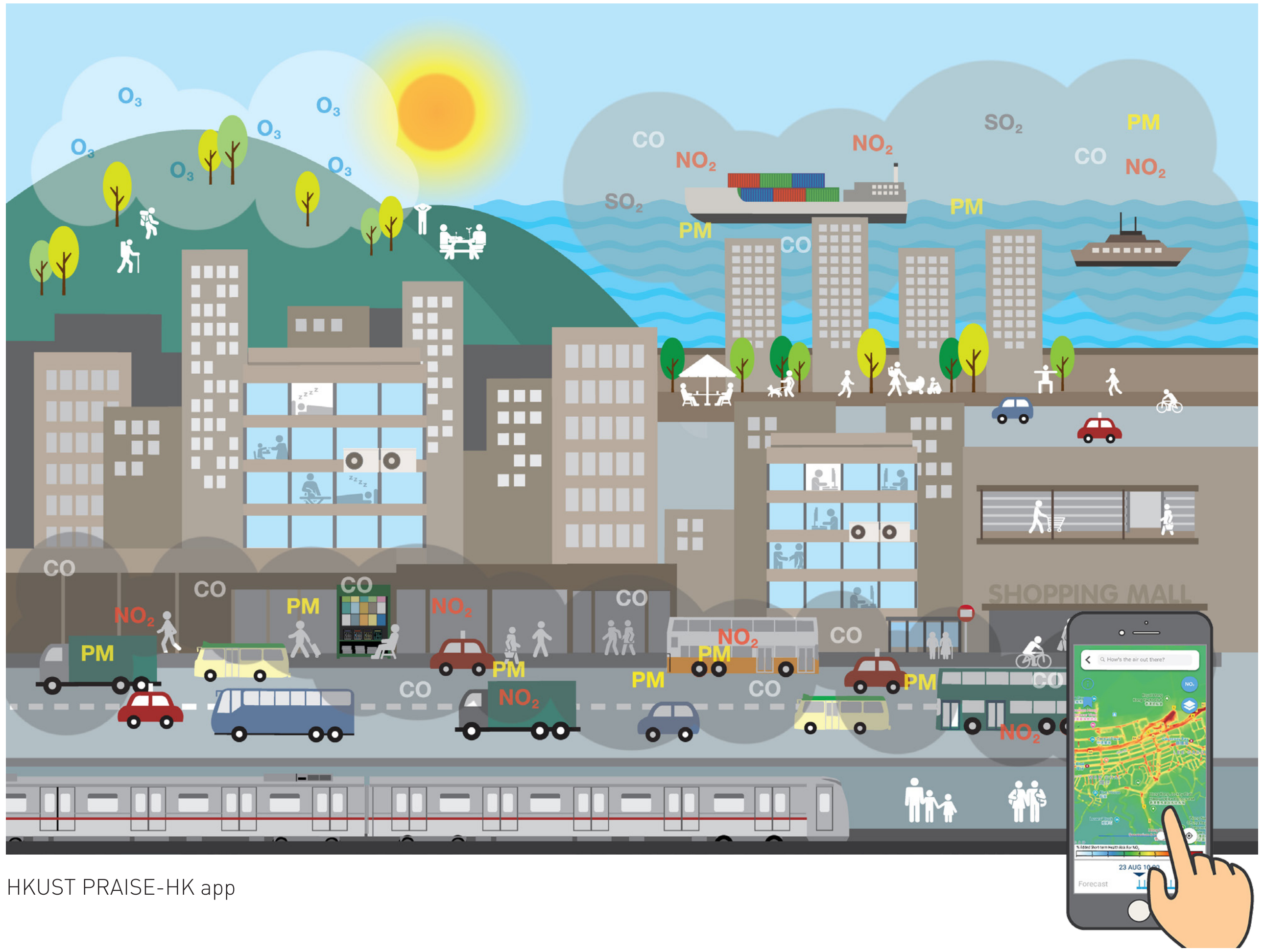
POWERING CHANGE

The tiny size of sensors involved in ubiquitous and contactless sensing does not allow much room for bulky batteries, making energy consumption a major issue. Prof Qian Zhang and her team leveraged the reflective properties of Internet-of-Things devices along with radio frequency signals already in the environment – including television and Wi-Fi, known as ambient backscatter – to eliminate the need for a battery. In a prototype of a battery-less pair of shoes, the team designed energy harvesting insoles, power management circuits, and an ambient backscatter module, complete with Bluetooth, to support its many applications. The team was the first in the world to achieve such an energy-harvesting platform in shoes *(IEEE INFOCOM*, 2017*)*.



Sensors such as an accelerometer, pulse sensor, and energy harvester are installed in the left shoe to register activity. The heat and kinetic energy harvested during walking is then used to transmit the activity to the other shoe through ambient backscatter, which is finally wirelessly communicated to the user's smartphone, without the need of a battery.

BREATHING SPACE



HKUST PRAISE-HK app

In addition to novel ways to boost healthy sleeping and eating, HKUST researchers are empowering individuals to manage air pollution-related health conditions, such as allergies and asthma, and their overall well-being. This is being advanced through a first-of-its-kind mobile app combining world-leading air quality and transport modeling systems, exposure science, and big data analytics.

The initial phase of the three-stage project was completed in June 2019, with the app's public launch in Hong Kong. In its current phase, the technology is assisting users to manage and reduce their personal exposure to air pollutants while on the move around the city. It does so by providing real-time street-level air quality information that allows users to take bad-air avoidance strategies when planning their routes. In later stages, it is expected to track indoor environments as well.

Moving Around

The five-year initiative, funded by HSBC's 150th Anniversary Charity Program, is known as the Personalized Real-time Air Quality Informatics System for Exposure – Hong Kong (PRAISE-HK). Its multidisciplinary HKUST research team is being led by air quality management expert Prof Alexis Lau. Among its breakthroughs, the project introduces the novel paradigm of managing personal exposure to pollution rather than the current air quality concentration management that focuses on controlling for average concentrations.

"Exposure here means how much air pollution a person experiences in a 24-hour period, not only when going to work, and walking around the streets, but also what he or she may be exposed to in their office and at home," Prof Lau said. "We aim to give people their air exposure patterns and then make suggestions as to how they may reduce such exposure."

A Healthy Approach

Air quality at a particular location is affected by diverse factors, such as the source of air pollution, degree of traffic congestion, and wind direction. Prof Lau and his team have integrated all these factors through real-time data obtained from the Hong Kong government's Transport and Environmental Protection Departments in a unique data-fusion system. The team's novel algorithm is the intelligence behind the data modeling, and is capable of achieving unprecedented forecast accuracy of an index of agreement of more than 90%.

For a highly-urbanized area like Hong Kong, real-time availability of traffic conditions on major roads is another key element that contributes toward higher-accuracy analysis of emissions from transport, a part of the project guided by the expertise of dynamic transportation specialist Prof Hong Kam Lo. To make this feasible, Prof Lo built a dynamic public transport modeling system that leverages and enhances open-source traffic simulator software MATSim, Hong Kong's road network, and data on how and when people travel. The novel planning system can model travel plans down to the individual level in what the researchers refer to as "activity-based modeling", providing assessment of traffic speed, volume, and transport emissions, and ultimately a more accurate picture of the air quality data at the roadside level.

"We could not deal with these types of interactions previously," he said. "Now, using the very detailed information available and big data analytical methods, we can fuse these variables into our system, a refinement that is not being done anywhere else."

PROF ALEXIS LAU
Professor of Environment and Sustainability, Civil and Environmental Engineering

> "When people thought about air quality in the old days, they would feel that controlling air quality was out of their hands. Now we are showing that a lot of things can be done"

The PRAISE-HK project will not only empower individuals, but also move overall air quality management to the next stage of development, enabling decision-makers to identify hotspots, target more precisely the causes of pollution, and define methods to improve the situation. Currently, if concentrations are deemed too high, across-the-board requirements are usually put in place on sources of pollution to control their emissions. "To boost public health, we need to go beyond improving the average. We need to understand where and when people have their highest exposure to pollution and target those areas for improvement," Prof Lau noted. The research is being conducted in conjuction with the World Health Organization, United States Environmental Protection Agency, and other international scientists and agencies.

PRAISE-HK INTERFACE

Air Quality Health Index (AQHI) | Risk composition | 48-hour air quality forecast | Spatial distribution of AQHI | Frequented locations | Health advice based on real-time air quality

Phase I – Real-time High-resolution Air Quality Map
(Launched June 2019)
Users can tap a map on the PRAISE-HK smartphone app to review outdoor air quality at any location in the city (sensitivity of up to 2m), along with the health risks associated with such air quality, to guide them to choose healthier routes or destinations. The app is also capable of displaying a 48-hour air quality forecast at said locations as well as providing health alerts.

Phase II – Air Pollution Total Exposure Health-Risk Review
(Targeted launch – June 2020)
This will include readings from selected indoor locations as well as outdoor environments to provide a total exposure review of a person's travel history and to plan future itineraries that avoid particular air pollution hotspots. Such capabilities bring air management down to the individual level. Highly-accurate portable sensing devices were designed to obtain indoor to outdoor air quality ratios, such as high-rise and underground levels, to establish baselines. In this phase, users can opt to input their personal health data that changes due to air quality.

Phase III – Personal Air Quality & Health Alert Generator
(Targeted launch - December 2021)
The final phase will include a personal air quality and health alert generator, built on data from the first two project phases. The function is capable of alerting and giving user recommendations, given that each person's lifestyle is likely to be different.

STEPPING FORWARD

Our own two feet have often been left out of the planning strategies for urban transportation systems in the past. In a push for healthier urban living, this is set to change, especially in Hong Kong, where the government announced in the 2017 policy address that "walkability" would be given fresh emphasis as a way of moving around.

The city's existing approach to urban planning prioritizes vehicular traffic, while improvements to pedestrian traffic are often made through retrofitting pedestrian facilities. Now, data collection via location-aware sensors such as smartphones, has opened up urban informatics and big data analytics related to people's real activity patterns – how they travel, organize themselves, and use infrastructure.

To inform the smart policies that will help Hong Kong lead the way in developing strategies to promote walkability, Prof Hong Kam Lo draws upon his expertise in dynamic and stochastic traffic modeling. Prof Lo, along with fellow researchers, is in the process of building Hong Kong's first walking choice model through algorithms developed using multiple sources of data input. By building an intricate integrated building information modeling-3D geographic information system (BIM-3DGIS), the modeling system will enable network accessibility analysis and 3D visualization, along with walking utility functions based on econometric analysis. The three-year "Walkability" project was launched in 2018 under the Strategic Public Policy Research Funding Scheme of the Policy Innovation and Co-ordination Office of the Hong Kong government.

> "By making walkability an integral part of transport policy-making, Hong Kong can be an example to the world"

PROF HONG KAM LO
Chair Professor and Head, Department of Civil and Environmental Engineering

Walking choice models are highly complex as they need to incorporate numerous microenvironmental variables in the analysis, including issues such as whether walkways are sheltered, their width and slope, the existence of stairs, and the quality of the pavement, among others. Focusing specifically on the Hong Kong urban areas of Kwun Tong and Tsuen Wan, the project uses extensive survey data collection to analyze people's propensity for walking, what infrastructure they are looking for or trying to avoid, and the concerns of special needs groups, such as the elderly and physically challenged. For example, the research team's preliminary analysis has shown that, on average, people are willing to walk an extra 17 meters to avoid every vertical meter of stairs.

The team's walking choice model will provide insights into who would benefit from a particular initiative, and how. Such evidence-based information is critical in justifying infrastructure investment. They will also undertake policy analysis and provide options for the government to make the city more pedestrian-friendly.

HKUST GREAT SMART CITIES INSTITUTE: BUILDING A SMARTER AND BRIGHTER FUTURE

Green, resilient, empowering, adaptable, and transformative – HKUST's GREAT Smart Cities Institute seeks to advance science and technology for smart city development in all these ways, and more. The Institute's diverse, cross-disciplinary research projects and applications include the PRAISE-HK mobile app, Walkability, Smart Urban Water Supply Systems (see *Research@HKUST*, 2017), and Mitigating Urban Debris Flow (see *Research@HKUST*, 2017), among other large-scale projects. The Institute also seeks to guide policy formulation and foster the next generation of professional urban planners.

SMART ECO-FRIENDLY BUILDINGS

Hong Kong currently has the world's second greatest carbon footprint per capita, with functioning buildings making up more than 50% of total energy consumption and using 90% of the city's electricity.

Now, imagine a building that turns the temperature in a room up or down, depending on the number of people inside – without human intervention. A building with the capability to sense when a dangerous gas is being emitted and also alert managers or owners ahead of a hazardous build-up. An institution with low-power, high-performance air conditioning, where energy consumption can be monitored down to each room while still achieving thermal comfort. All using practical, low-cost technologies that are energy efficient and environmentally friendly.

These are the advances being realized in two wide-reaching projects under the HKUST-MIT Research Alliance Consortium, with funding from the Hong Kong Innovation and Technology Fund. Both aim to make it possible for such developments to be commercialized into widely-available products that will assist the reduction in energy usage and carbon emissions; and are using Hong Kong as a platform to showcase the beneficial implications of their advances to the world.

Flow measurement sensor that is compact and low-cost in design, without the usually bulky packaging for conventional flow measurement tools. Through integration with a micro-controller unit, sensor fusion, and the control program, a new thermal comfort-based HVAC system with artificial intelligence can achieve 20% energy saving in comparison with commercial HVAC systems.

Intelligent Heating, Ventilation and Air-conditioning (HVAC) system seeks to reduce carbon footprint in indoor environments.

Air quality sensor that can operate at room temperature to monitor any gas leakage and alerts. The capability to operate at room temperature helps reduce power consumption by 200 times, compared with conventional tin-oxide sensors. The sensor utilizes nanostructured materials and a CMOS chip to sense an array of channels with their own signal conditioning circuitry and analog-to-digital converter (ADC) to detect and distinguish between different gases. A patent has been filed.

Environmental energy harvesting technology maximizes energy extraction from two sources in the environment – solar and radio frequency (Wi-Fi) – to generate electricity to enable self-powered multi-sensing devices and their sensors. Antenna research also helps to maximize Wi-Fi energy harvesting by using a multiple orthogonal design that can collect ambient radio frequency from different alignments and then convert it.

Image sensor detects if a room is occupied or vacant, and triggers environmental adjustments, such as air conditioning and lighting. It can also alert building management when a human has entered a particular area. The HKUST complementary metal-oxide-semiconductor (CMOS) image sensor uses an analog-to-information converter (AIC) rather than the traditional ADC for comprehensive imaging and processing, and its power consumption is one of the lowest in the world.

Smart water quality sensor recruits genetically engineered *E. coli* to autonomously detect water contaminants, such as cadmium and zinc, by harnessing biological sensor systems for contaminants. For pollutants beyond natural sensing systems, synthetic *E. coli* are engineered to serve as fluorescent light indicators to show the concentration of particles in a sample. Also included are an optical sensor that responds to and measures the intensity of fluorescent light emitted by the *E. coli*, as well as circuits for data collection and transmission.

Smart Self-powered Multi-sensing Technologies

In the first project, coordinated by electronic and computer engineer Prof Chi Ying Tsui, a next-generation series of low-power and cost-effective sensors for measuring and analyzing images, air quality, water quality, temperature, humidity, and thermal insulation, is underway.

The sensors are integrated into a single multi-sensing device equipped with novel energy harvesting and power management technologies, allowing the device to power itself autonomously. Meanwhile, low-power radio frequency (Wi-Fi) communications as well as integrated circuit and system-level innovation provide the capability to transmit critical information to a base station or trigger an alarm. There is no need to connect the sensor devices to the mains, thus reducing the costs of installation, widening the options as to where they can be deployed, and lowering overall maintenance costs.

> We have set ourselves really stringent specifications of low power, low cost, self-calibration, and integration to be the driving force of innovation

PROF CHI YING TSUI
Professor of Electronic and Computer Engineering,
Head, Division of Integrative Systems and Design

The energy harvesting technology is based on Prof Tsui's expertise in multiple-input, multiple-output (MIMOs) power management technology research, ongoing since the early 2000s. Prof Tsui's team employs a combination of solar and radio frequency energy sources to generate output for use in the sensor, the charging up of the small battery inside the integrated device, as well as wireless communication.

The key innovation lies in the new MIMO power management architecture that maximizes energy extraction and conversion. Intelligent circuits have been designed to ensure the solar cell is operating in conditions that will maximize its power and reduce its loss during conversion from solar to electrical power.

In the longer term, the project's novel technologies could also be employed in applications as diverse as toys and odor detectors in fridges.

MEMS and Carbon Footprint

In the second research project, coordinated by mechanical engineering specialist Prof Yi-Kuen Lee, an intelligent heating, ventilation and air-conditioning (HVAC) system is being developed to reduce the carbon footprint in indoor environments. In Hong Kong, air conditioning in high-rise buildings accounts for around 30% of total energy consumption.

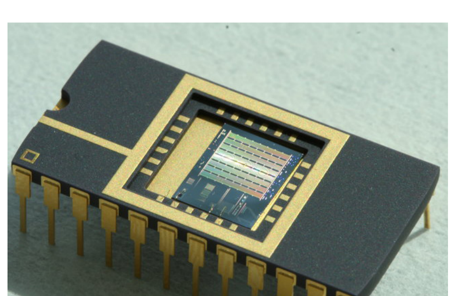
Prof Lee focuses on developing novel micro-electromechanical (MEMS) flow sensors. MEMS are tiny devices with moving parts, such as sensors, gears, and valves that are embedded in semiconductor chips. The aim is to develop a low-cost micro-energy sensor that can be deployed in each room, or different zones of buildings, providing a more detailed breakdown of energy consumption (for example, hourly, daily, monthly) than previously feasible, to help buildings achieve greater energy efficiency.

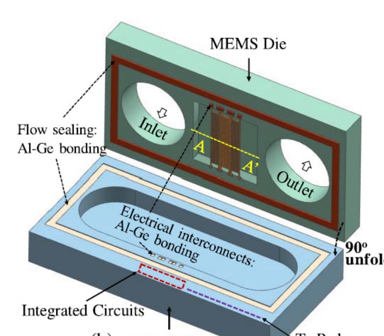
The HKUST researcher's innovative "system-on-chip" design comprises a compact, low-noise and low-power complementary metal-oxide-semiconductor (CMOS) thermal flow sensor to measure two-dimensional air velocity, when traditional flow measurement tools only make measurements in one dimension.

> While some people say fundamental research is impractical, it actually provides a great foundation to work on technology

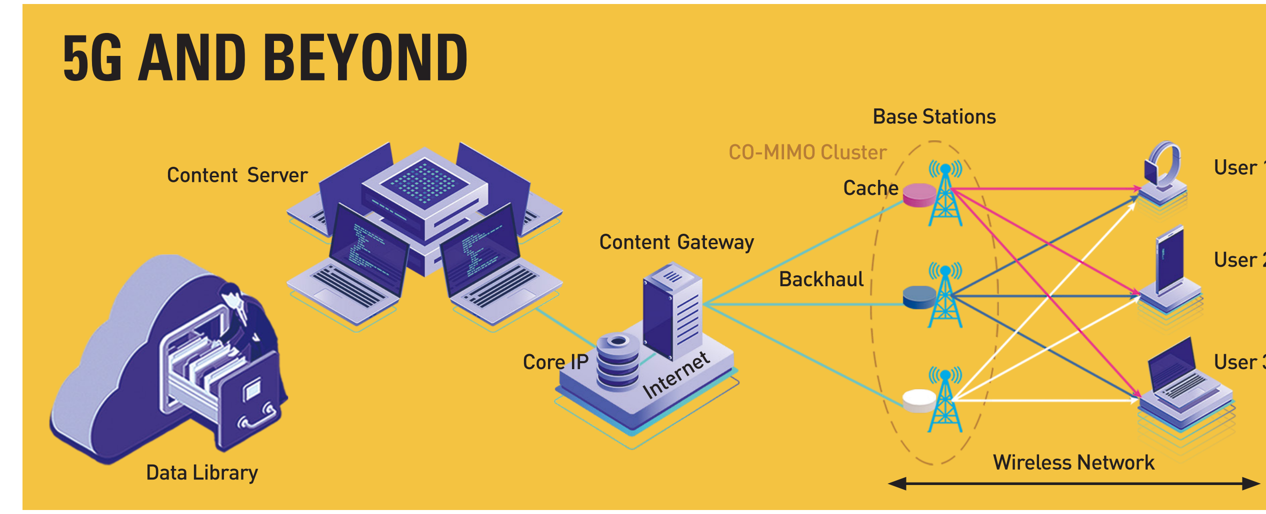
PROF YI-KUEN LEE
Associate Professor of Chemical and Biological Engineering, Mechanical and Aerospace Engineering

Prof Lee has optimized the system-level design through developing a general compact 1D model and collaborating with a commercial foundry to align the design with mature CMOS fabrication technology. The integrated design can significantly improve flow measurement accuracy to 1.6 millimeters per second, better than 3.8 millimeters per second according to the air speed standard of the United States using expensive optical instruments. It is able to provide a much quicker way to analyze sensitivity and power consumption to optimize devices and microsystem integration than employing time-consuming computational fluid dynamics models. Indeed, Prof Lee's theoretical flow sensor model could do the job a million times faster.





LEFT: Fabricated flow sensor chip; **RIGHT**: Wafer-level encapsulated flow sensor with readout integrated circuit and packaging design



Prof Lau discovered that a cache can be used at the edge of a wireless network, or base station, to store data such as a popular YouTube video that many users are trying to watch simultaneously. His novel physical layer caching technology transforms the underlying topology to significantly boost the transmission bit rates and capacities.

The recent arrival of fifth-generation (5G) mobile networks promises faster and more reliable mobile connections, with forecasts of 1,000 times greater demand capacity, and 500 billion devices connected to the Internet by 2030. The era of mobile connectivity being ushered in by 5G is expected to drive significant progress in entertainment, logistics, mobility, health, and other technologies, with some examples discussed earlier in this chapter.

A significant avenue to facilitate such development is a new "application-aware" framework where the individual needs and characteristics of different applications can be identified and utilized by the network for greater efficiency. Prof Vincent Lau, an expert in wireless information technology, is at the forefront of such advances.

Speeding Up with Physical Layer Caching

One example of "application awareness" that Prof Lau has pioneered is "physical layer caching", which helps the wireless network deliver contents rather than random information.

Caching is beneficial as it stores data and reduces the number of hops that a packet of data has to make between the server and the user's computer. Prof Lau's research team is the first to make the groundbreaking discovery of using a cache at the edge of a wireless network, or base station.

Through cooperatively sharing data between base stations, Prof Lau's innovative Physical Layer Caching Model transforms the underlying architecture of the wireless network, from a less favorable interference channel topology to a more favorable broadcast channel topology, resulting in a significant boost to the transmission capacity. In doing so, the presence of caches at base stations improves speed and lowers the power requirement. Alternatively, using the same amount of power, the network can achieve a much higher bit rate or support more users.

> Future wireless networks will be integrated with applications in our everyday life

PROF VINCENT LAU
Chair Professor of Electronic and Computer Engineering

Prof Lau became the first to publish on physical caching in 2013. His work has led to the discovery of storage as a new resource metric, in addition to the well-known power and bandwidth, to support content-centric communications.

A more challenging issue for Prof Lau is developing a caching algorithm to help the network decide what it should be caching, given that a base station always has limits on its storage capacity. This may help the industry set new standards for 6G wireless systems because caches have never been used at base stations before.

Mission Critical Control – Safer, More Reliable

A second example of "application awareness" is integrated design for specific applications to achieve better performance in mission critical control, for example, autonomous vehicles' capability to avoid collisions. In this application, the goal of the wireless network is not only to maximize information capacity but also to achieve stabilization in a potentially unstable dynamic system through feedback control.

Prof Lau has combined his long-held interest in both communication and control theories to design a novel ultra-low latency multi-access protocol, by harnessing the signals transmitted by different sensors over the same radio resource block as well as developing an allocation algorithm that provides a flexible priority function to avoid congestion collapse when there are too many information requests from Internet-of-Things (IoT) sensors.

Such tactile latency can only be achieved with ultra-low latency communications enabled by 5G and beyond systems.

BEHIND THE BREAK-THROUGHS

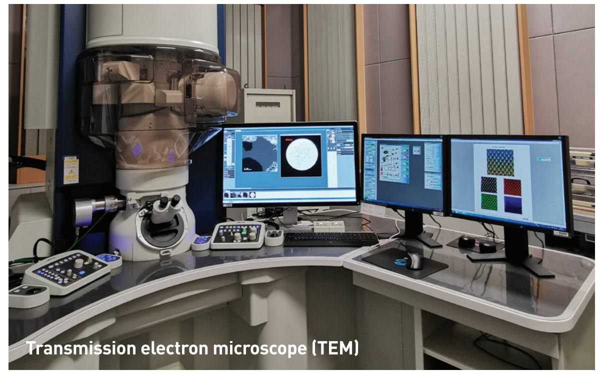
First-class minds drive first-class research. But leading-edge facilities are also a key factor in bringing breakthroughs to fruition. A special way that HKUST has supported its faculty and students right from the University's establishment in 1991 is through its Central Research Facilities, the first-of-its-kind set-up in a tertiary institution in Hong Kong.

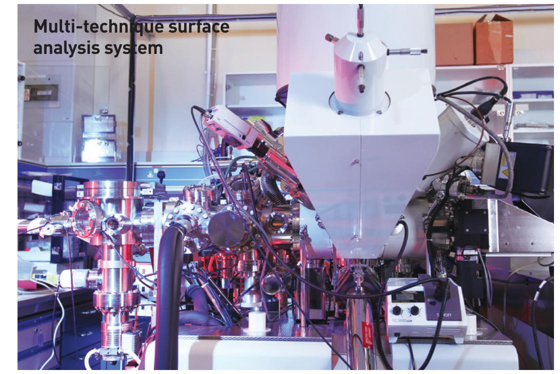
This concept of central core facilities offers more than just shared, advanced equipment, which are often too high-maintenance and expensive for the individual faculty's budget, and require specialized locations. Users also benefit from the scale of such facilities and the support from highly-skilled technicians with specialist instrumentation and technical expertise. Together, such elements provide a holistic setting for research and for nurturing the next generation of scientists.

The suite of nine Central Research Facilities, encompassing realms such as environmental and geotechnical studies, advanced engineering materials as well as design and manufacturing services, houses an array of large-scale and state-of-the-art equipment to facilitate collaborative research among faculty and students. With most of them operating 24/7, the Facilities continuously support faculty and students within HKUST, as well as researchers from other universities and industry in Hong Kong, and beyond.

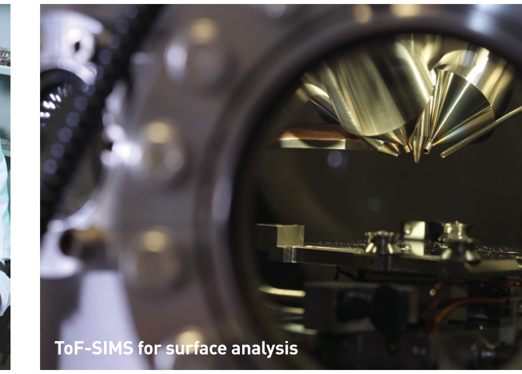
In this issue, we highlight the Materials Characterization and Preparation Facility and Nanosystem Fabrication Facility, both unique in Hong Kong, and the most extensive and comprehensive of their kinds in the region.

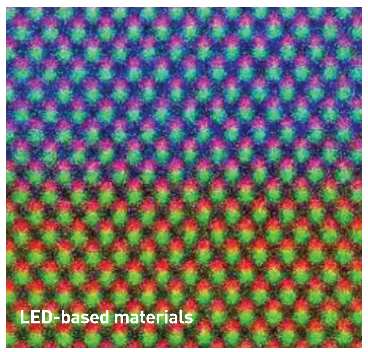

Electron beam lithography system

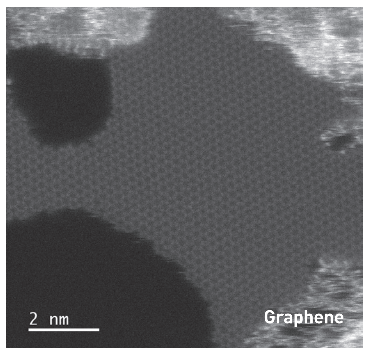

Transmission electron microscope (TEM)


Multi-technique surface analysis system

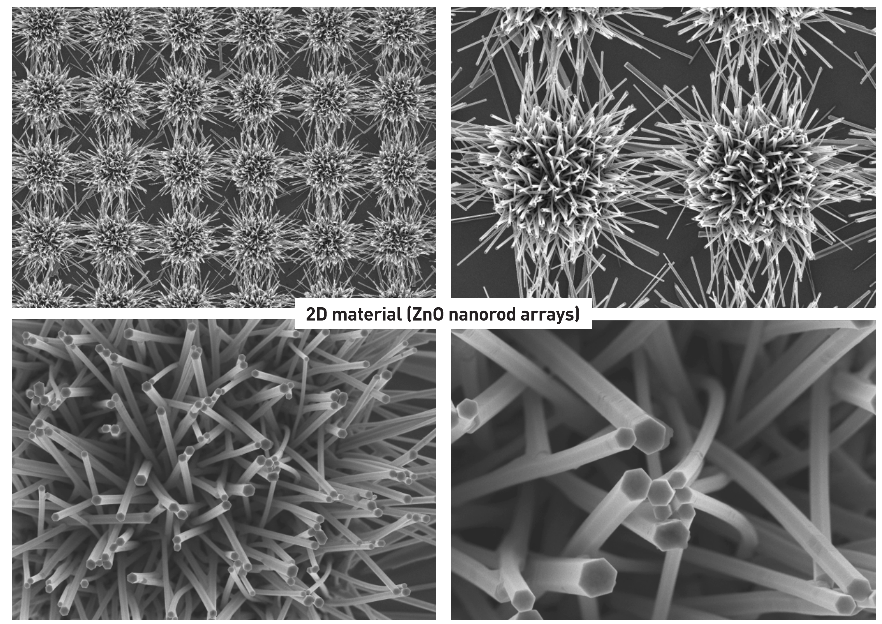

Scanning electron microscope (SEM)

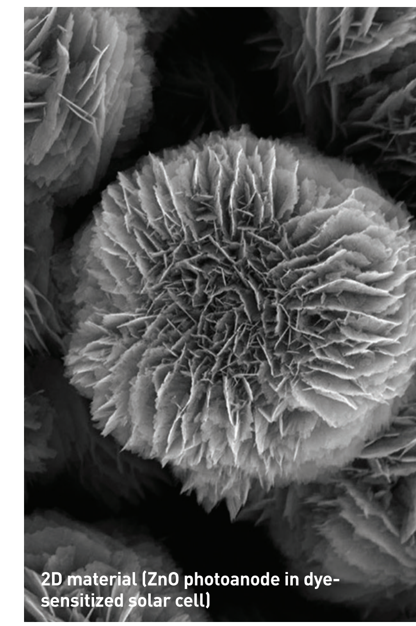

ToF-SIMS for surface analysis

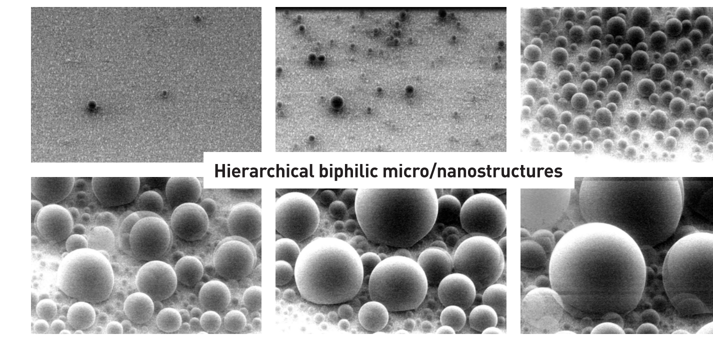

LED-based materials

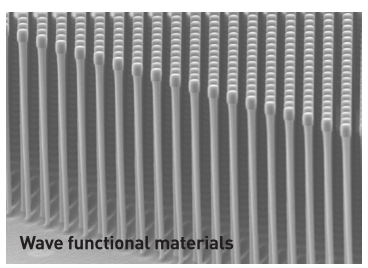


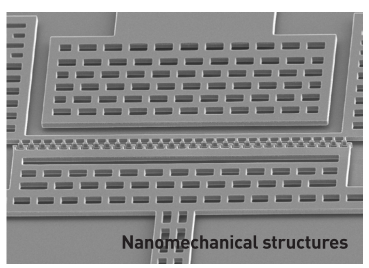
Graphene

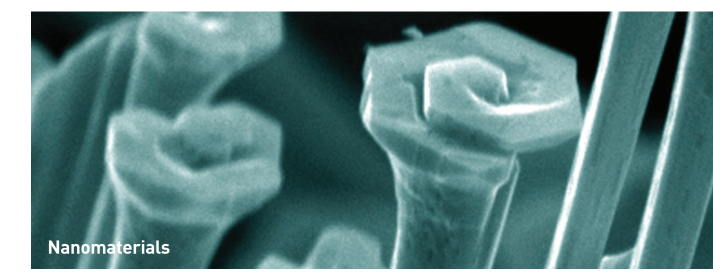

2D material (ZnO nanorod arrays)


2D material (ZnO photoanode in dye-sensitized solar cell)


Hierarchical biphilic micro/nanostructures


Wave functional materials


Nanomechanical structures


Nanomaterials

PAVING THE WAY TO NEW MATERIALS

In Lab 2212, Hong Kong's first and only transmission electron microscope with sub-angstrom resolution, towers over researchers who are using it to probe the tiniest quantum dots in the samples of superlattice alloy indium gallium arsenide (InGaAs) and gallium arsenide (GaAs). The researchers employ the huge microscope to reveal the arrangements of atoms at the interface in the material, one important step in the development of next-generation highly sensitive light-emitting diodes (LEDs).

The rocky hillside on which HKUST is built has a particular advantage for the scientific discoveries being undertaken in Lab 2212. It provides a vibration-free foundation for its state-of-the-art microscopes, where the tiniest movement could distort the readings of high-resolution instruments. Temperature, controlled through a flow of water within the lab's specially tiled walls, as well as humidity and cleanliness, are other key constants that are painstakingly calibrated.

This is the world of the Materials Characterization and Preparation Facility (MCPF), encompassing 12 main laboratories and more than 40 pieces of highly-specialized characterization equipment to help researchers investigate the properties of a large range of materials – electronic, polymers, soft, organic, biological, and thin films, for example – and carry out novel scientific and engineering investigations, including sample preparation, optical characterization, surface analysis, electron microscopy, scanning probe microscopy, electrical and magnetic characterization, thin film deposition, thermal analysis, X-ray diffraction, and nanofabrication.

Here, researchers are equipped with the capabilities to probe and measure the composition, morphology, structure, and properties of materials that may shape technological innovation and our future world.

And with the power of such technology on hand, HKUST researchers have achieved major breakthroughs over the years, from the discovery of the world's smallest carbon nanotube and its associated superconductivity, to the ground-breaking development of noise-controlling resonant sonic materials, and environmentally-friendly organic solar cells performing with record efficiency.

Behind these breakthroughs is a team of 17 dedicated personnel, of which seven have PhDs and the expertise to maintain and operate the equipment, help users in the interpretation of data, and run training workshops to help users build research skills. The Facility also benefits graduate students through providing experiential hands-on learning opportunities.

New analysis techniques and methodologies are constantly being developed, ensuring that the MCPF can meet the fast-evolving needs of science and engineering, and serve the University's own faculty and students, as well as major external users. "In the University's early years, the Facility was equipped for investigating traditional materials. Now we are working on nano and quantum materials. We can manipulate materials at the atomic level to produce new synthetic functional materials, with properties not available in natural materials," Prof Ning Wang, MCPF Director and Chair Professor of Physics, said.

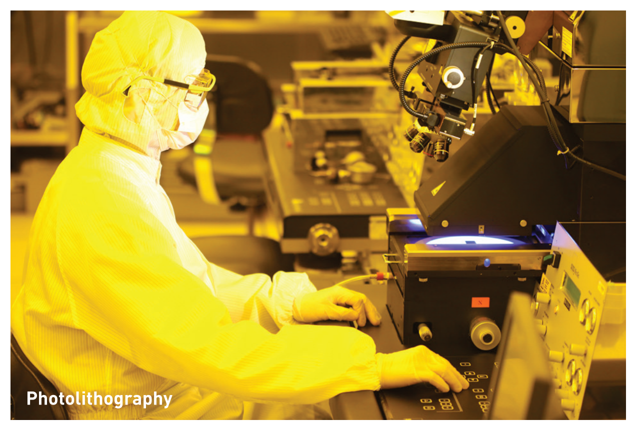
Established in 1991, MCPF is the first, and to date still the largest, central research facility in materials preparation and characterization in Hong Kong.

> "We can manipulate materials at the atomic level to produce new synthetic functional materials, with properties not available in natural materials"

PROF NING WANG
Chair Professor of Physics
Director, Materials Characterization and Preparation Facility


Over 750 square meters of meticulously controlled cleanroom space


Growing materials


Photolithography


Metal deposition


Mask making


Dry etching


Wet etching

Researchers start by choosing the substrate, then move on to print micro or nano-sized patterns onto the substrate by a lithographic process, followed by the etching of patterns onto the wafer. Layer by layer, a system takes shape. To make a modern device or system, each process/layer needs to be meticulously controlled, often involving multiple advanced tools being used with great precision and good throughput, as well as at high temperatures (>1000 ºC) - all at an unimaginably small scale (one micrometer is a thousandth of a millimeter; one nanometer is a millionth of a millimeter).

NANO RECIPES FOR CHANGE

The Nanosystem Fabrication Facility (NFF) is among HKUST's flagship research facilities, which NFF Director Prof Andrew Poon likens to an "open kitchen". But this is no ordinary kitchen. Here, scientists and engineers, working at the infinitesimal nano and micro levels, can experiment with and try out different "recipes", i.e. fabrication methods, to identify optimal materials, structures, and methodologies for making novel devices and systems on a wafer. It's like making a pizza, only with minuscule ingredients patterned over layers sitting on a substrate.

A "recipe" often involves a few tens of steps, from growing materials to metal deposition, and layers of structure. Each step would require a particular timing and duration; a particular dosage or temperature; and also particular tools being used in a certain sequence. But like a food recipe, if any step fails, the "chef" may need to adjust the recipe by modifying the combination of materials, processes or tools in novel ways, and start all over again. "Only by trial and error can the 'chef' develop the next 'Michelin-starred recipe'," explained Prof Poon. "There is no shortcut to success."

This intriguing world is the gateway to harness the latest technologies, for example, super-high-density microprocessor and memory chips, high-storage capacity batteries, and high-efficiency solar cells. The challenge is to build devices that are smaller, faster, as well as more functional, energy-efficient, and flexible, than those currently available.

Established in 1991, the NFF has undergone extensive upgrades to keep up with technological advances. Starting out with a focus on electronics, the Facility has expanded its reach and is now equipped with extensive capabilities to assist nanotechnology researchers in investigating numerous different materials, from the traditional silicon to exotic materials such as graphene and other carbon-based nano structures.

The NFF's "kitchen" now houses 64 pieces of state-of-the-art equipment in two meticulously controlled cleanrooms. "It is essential to keep a 'clean kitchen' to avoid 'cross-contamination'," said Prof Poon.

Working hard and staying at the forefront of technologies, the NFF has contributed to many firsts, for example: development of the world's first full-color micro-LED projection display; a revolutionary thin-film transistor technology for high-definition liquid crystal and Organic LED displays; and a silicon micro filter based on silicon-on-insulator (SOI) for circulating tumor cells (CTC) isolation, which can achieve a significantly increased efficiency and accuracy.

Another important ingredient in the recipe is the NFF technical team. "Our users inspire us," Prof Poon said. "There is deep interaction between the users and our technical team, and through such collaboration, researchers and facilities develop together to meet evolving research challenges."

Like MCPF, the NFF reaches beyond the University. Prof Poon has recently established the Greater China Nano Fabrication Consortium, which is building a network to link up university-based researchers and companies in Hong Kong and the Greater Bay Area.

"We are proud to have been a key part of our faculty's research process and to have contributed to numerous breakthroughs. I like to think of NFF as one of the 'crown jewels' of HKUST"

PROF ANDREW POON
Professor of Electronic and Computer Engineering
Director, Nanosystem Fabrication Facility

PROF ZHIYONG FAN
Professor of Electronic and Computer Engineering

“Seeing is believing! We have really powerful equipment at the MCPF to see the morphology, shape, structure, and properties of the materials at the micro and nano scale. And with the NFF, we have a state-of-the-art facility to make devices. We are lucky to have both”

Prof Fan engineers novel nanostructures and functional materials with enhanced performance for a variety of applications, including energy conversion, electronics, and sensors.

PROF PING GAO
Professor of Chemical and Biological Engineering

“The MCPF has been one of the central contributing factors in HKUST’s success, and a model for many institutions since its establishment”

Prof Gao’s research in advanced nanomaterials, including graphene, 2D materials, novel polymers, and polymer composites, has far-reaching applications – from drug delivery to energy storage and environmental engineering applications.

PROF KEI MAY LAU
Fang Professor of Engineering

“It would be difficult for individual faculty to afford or maintain the advanced equipment contained in the NFF and MCPF. Their indispensability cannot be understated!”

Prof Lau develops high-performance next-generation compound semiconductor materials for microelectronic applications. These include LED displays, mobile phones, and other electronic gadgets.

PROF BAOLING HUANG
Associate Professor of Mechanical and Aerospace Engineering

“The NFF is essential to our research. My colleagues and I spend 80% of our time working on ‘recipes’ and trying out different fabrication methods to identify the best methodology”

Prof Huang studies micro-devices and sensors, including micro-coolers for noise reduction and signal-to-noise ratio improvement, among others.

EQUIPPED FOR SUCCESS

To many HKUST researchers, both the Materials Characterization and Preparation Facility (MCPF) and Nanosystem Fabrication Facility (NFF) are crucial to their search for new scientific and engineering frontiers. Both facilities are often required in the multiple rounds of observation, fabrication, characterization, and adjustment, along the journeys that start with ideas and end in innovations. Working synergistically to support this process marked by perseverance and ingenuity, both the MCPF and NFF have played continual and integral roles in equipping HKUST’s researchers for success.

PROF HONGKAI WU
Professor of Chemistry, Chemical and Biological Engineering

“I build micro tools to study cell response and cell-to-cell interaction. To do this, I need the right set of tools as well as technical support. The NFF gives me both”

PROF ANGELA WU
Assistant Professor of Life Science, Chemical and Biological Engineering

“There’s a very human aspect to NFF – they listen to feedback and try their best to meet our needs. For instance, they have carved out a station for microfluidics research after popular demand”

Both professors’ work at the leading edge of microfluidics, provides the enabling tools to investigate research problems in life science and medicine.

PROF LEVENT YOBAS
Associate Professor of Electronic and Computer Engineering, Chemical and Biological Engineering

“The NFF offers an industry-like environment in a university setting with all the flexibility required for custom-made research processes and none of the rigidity of industry practices. At HKUST, we have the best of both worlds”

Prof Yobas develops microfluidic and nanofluidic devices for a wide range of biomedical applications.

PROF HO BUN CHAN
Professor of Physics

“HKUST is the only university in Hong Kong that has its own liquid helium plant. It allows us to conduct low-temperature experiments in an economical way. It is a huge asset to HKUST”

Prof Chan’s research focuses on micro and nano-electromechanical structures for smart devices. He also explores the interaction between components at the nanoscale for wide-ranging applications in sensors as well as fundamental physics experiments.

PROF FRANCESCO CIUCCI
Associate Professor of Mechanical and Aerospace Engineering, Chemical and Biological Engineering

“MCPF has one of the best technical teams in the world. They are experienced, hardworking, and always willing to teach and guide the students”

Prof Ciucci works on functional materials with applications in fuel cells and batteries.

MUHAMMAD SIDDIQUI
Final-year PhD student, Civil Engineering and Environmental Engineering

“The MCPF staff is always willing to go the extra mile. Their guidance and support have been instrumental in helping students produce high impact-factor papers”

Muhammad uses the scanning electron microscope, X-ray photoelectron spectroscopy, and X-ray fluorescence in his research on self-forming membranes for wastewater treatment.

(Left to right) Dr Sherman Fang, Prof Johnny Sin, Mr Arthur Chan, Prof Gary Chan, Mr Dick Tang, Ms Zernain Athar, Prof King Lun Yeung, Ms Trixie Ruth DY

FROM LAB TO REAL LIFE

Meet some of the HKUST researchers whose innovations are moving to market

THE SUPER-CLEAN TEAM

The battle to beat disease-causing microorganisms has found a new champion in a highly effective series of smart and effective disinfectants made possible by HKUST technologies. The multifaceted innovations by chemical and biological engineering expert Prof King Lun Yeung and health and environmental safety specialist Prof Joseph Kwan combine their expertise to develop novel materials and technologies to beat back airborne diseases such as Middle East Respiratory Syndrome Coronavirus (MERS-CoV), influenza H1N1 and H3N2, and emerging hospital superbugs, including the methicillin-resistant *staphylococcus aureus* (MRSA), carbapenem-resistant enterobacteriaceae (CRE) and the notorious vancomycin-resistant enterococci (VRE). The pair also developed technologies to fight waterborne microorganisms, for example, *E. coli* and *legionella pneumophila* bacteria, as well as microorganisms that cause bad odor in drainage and sewer.

At the heart of the scientists' work lie three guiding principles:

- A "Safer-by-Design" approach that focuses on safety from inception of the idea – HKUST disinfectant products are designed with minimized use of ingredients or components. For example, while a typical shampoo product contains 20-30 ingredients, each HKUST disinfectant technology uses just two to three ingredients.

> "My goal is not a scientific journal paper, limited to what works in the lab, but a product that can eventually be brought to market"
>
> **PROF KING LUN YEUNG**
> Professor of Chemical and Biological Engineering, Environment and Sustainability

- Maximum effectiveness using the least amount of chemicals at the lowest cost – this has led to the adoption of the "continuous release" concept found in sustained drug delivery. The HKUST disinfectants are delivered in a very low dosage over a period of time to enable "release-killing", which then maintains the effectiveness of microbial sterilization over weeks or years. The dosage methodology also helps to reduce impact on the environment.
- Engineering that enables the technologies to be responsive to environmental cues – resulting in coated surfaces that can detect human touch and contaminating substances and deliver the disinfectant accordingly.

Prof Yeung's research, initiated in 2002 with a grant from Hong Kong's Innovation and Technology Fund, was spurred on by the SARS outbreak in 2003, the "Mexican" human swine flu outbreak in 2009, and management of health and safety concerns for major public events, such as the Beijing Olympic Games in 2008. While his goal is commercialization, the aim is not to operate his own business but to license the resulting technologies to up-and-running companies for speedier development to market and keep his own focus on innovation.

All the HKUST innovations adhere to US Food and Drug Administration and US Environmental Protection Agency standards for the use of germicides and their dosages.

Surface Disinfection

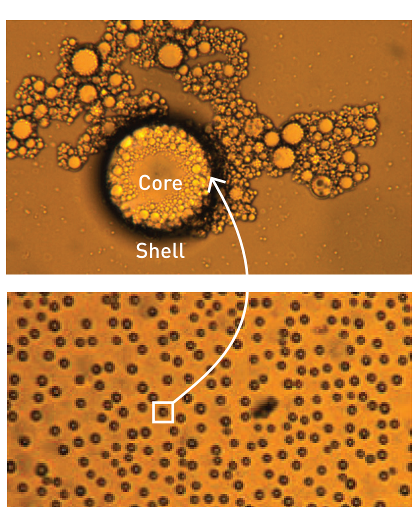
Smart Antimicrobial Coating

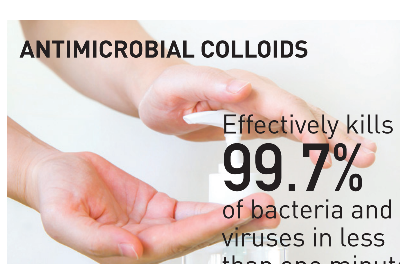
Chlorine dioxide, a disinfectant widely used in the food industry, was stored in smart capsules that control the release of the disinfectant, so that an extremely low amount is still potent enough to eliminate microbes. Catalytic-dyad and anti-adhesion materials engineered into the capsule provide contact-killing and prevent bacteria from contaminating the coating. They also enable the coating to sense touch from hand and contamination by droplets to automatically release larger amounts of the disinfectant to clean and disinfect the area of disease-causing microbes, viruses, spores, and mold. After numerous refinements of the release strength of the ingredients and encapsulation design, the biodegradable coating was shown to effectively kill 99.99% of bacteria, viruses, and spores within one minute of contact and remain effective for 30 days. The surface coating technology has been licensed to Greenland Biotech Ltd.

Antimicrobial Colloids

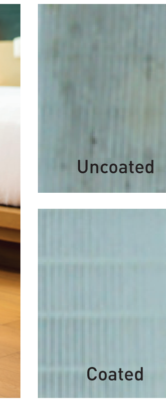
A related smart coating technology built from multi-level antimicrobial polymers kills microbes and prevents them from fouling surfaces. Findings show it eliminates 99.7% of bacteria and viruses in less than a minute. The technology can be formulated into different products including surface coatings, fabric softeners, paints, filters, hand soap, and disinfectant to afford long-term disinfection and protection against diseases. Clinical trials at the Kowloon Hospital show that it can drastically decrease bacteria on patient privacy curtains for more than three weeks. A study at elderly homes shows that its use on bed linens and pillows reduces microbial contaminations by more than 90% over seven days.

Surface Disinfection
HKUST's antimicrobial disinfection technology can be used in high-traffic surfaces. Smart capsules with diverse combinations of materials can achieve different effects, such as antifouling and slow release for continuous disinfection.

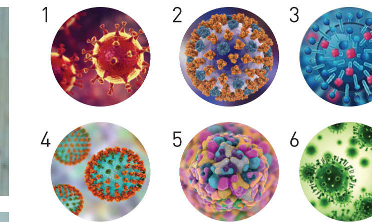




AIR DISINFECTION



HKUST's novel air purification technology was made available on the market as a household purifier in 2017



HKUST's smart coating can kill:
1. MERS-CoV: 98.8%
2. Influenza A virus: >99.999%
3. Influenza B virus: >99%
4. H3N2 Hong Kong flu virus: 99%
5. Enterovirus 71: >99%
6. H1N1 swine flu virus: >99.9%

Air Disinfection

Conventional HEPA (air) filters can sift and capture airborne microorganisms but the microbes may still remain viable, carrying the risk of recontamination. Applying HKUST's long-lasting antimicrobial coating technology to such filters has been shown to eliminate 99.99% of airborne bacteria and viruses, including MERS-CoV and influenza strains. The novel coating inactivates airborne microorganisms as they pass through the filter, preventing the accumulation of microbes on the filter's surface. Industry partner Chiaphua Industries Ltd has licensed and commercialized the technology into a product line called Germagic™.

Water Disinfection

Tap Water

Current disinfection technology uses high-input voltage pulsed electric field technology, requiring up to 100,000 volts and creating potential electrical hazards for operators. HKUST's Pulse Water renders microorganisms in water inactive by subjecting them to a repeated low-voltage pulsed electric field. This causes cell membrane pores to dilate, allowing chlorine in the water to rapidly kill the microorganisms. The portable, battery-operated technology has been miniaturized to maximize usage, being suitable for faucets and showerheads as well as public water systems. The HKUST researchers are also working with the Hong Kong government's Water Supplies Department on a two-year project to develop and field-test an antimicrobial formulation to keep pumps and pipelines clean.

Malodor Control

Strategies for dealing with unpleasant smells in a mixed-use, crowded urban environment have, to date, proved ineffective, expensive, or both. Now, a HKUST malodor control hydrogel, combining biocides, metabolic inhibitors, and catalytic agents, is being brought to market to suppress malodorous compounds. The technology reduces foul-smelling hydrogen sulfide to below 0.1 part per million (ppm) in sewers, drainage systems, as well as wet and dewatered sludge. Originally funded by Hong Kong's Innovation and Technology Fund, work is ongoing with the Hong Kong government's Drainage Services Department and Environmental Protection Department.

The hydrogel technology is now deployed in 200 locations across Hong Kong to control malodor. Only 4kg of hydrogel is needed to clean 200,000m³ of sewage water for 30 days.

ENERGIZING POWER MANAGEMENT

For decades, the electronics industry has been driven by "Moore's Law", a forecast that transistors on a microchip would keep doubling every two years, making faster, smaller, and cheaper devices continuously available. But as the smallest feature size for making a transistor has reached an almost unbelievable 5 nanometers, and that a transistor must at least measure a few nanometers to physically exist, Moore's Law is finally starting to change.

Instead of targeting size, the hi-tech sector's emerging goal is "More than Moore": an increase in functionality by adding device capabilities to the "brain" provided by the decision-making transistors. This could be in the form of sensors, or through passive components, as with Prof Johnny Sin's novel technology.

> "Engineering should benefit society by being useful and making life more efficient"
>
> PROF JOHNNY SIN
> Professor of Electronic and Computer Engineering

Prof Sin, one of the world's leaders in the microelectronic device field, has become the first globally to design embedded solenoid inductor microelectronic technology that has been experimentally proven to improve inductor efficiency by 6%. This is a huge saving in energy, given that many current solutions struggle to attain 1% improvement. In addition, the achievement has been accomplished using an area 5.5 times smaller than an "on-chip" inductor placed on the surface of the wafer.

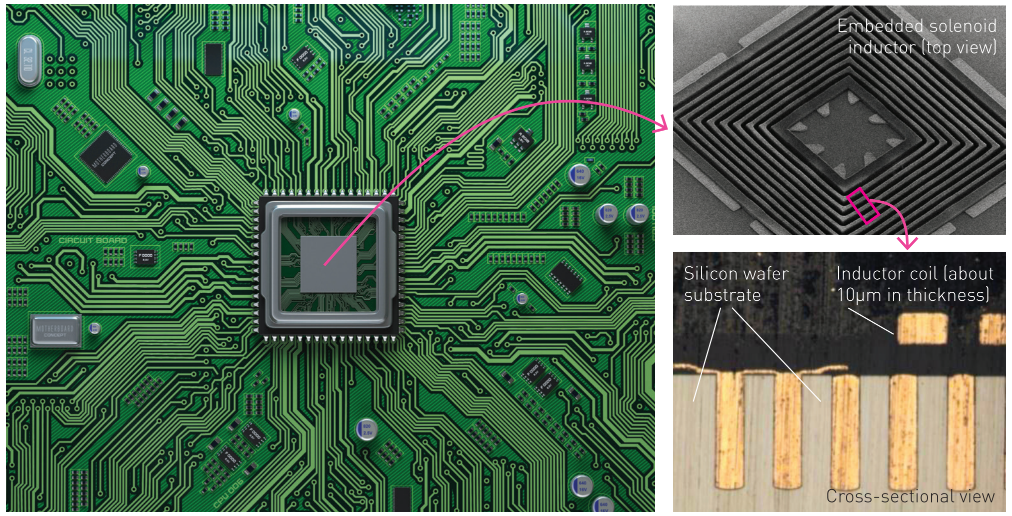
Utilizing this innovation, Prof Sin and his PhD students are now building novel power management integrated circuits to move energy storage and distribution, and the microprocessor industry, forward. Power management is a crucial element of any electronic gadget, acting as the distributor of energy held in the battery or from the mains in the wall and telling the gadget's functional components how to take in that energy. Eventually, such advances should help maximize battery life and reduce recharging of electric vehicles, mobile phones, and other devices.

The design work carried out over the past nine years with different PhD students has led to three generations of passive inductor technology. Under development are integrated power inductors for central processing unit (CPU) chips, micro-transformer chips for high-voltage isolated signal and power transfer, and integrated inductors for mobile and wearable electronics.

Confident that the team's ideas had major global commercial potential, Prof Sin and his first-generation PhD student Rongxiang Wu, now an academic at the University of Electronic Science and Technology of China in Chengdu, Sichuan, and third-generation PhD student Sherman Fang, decided to form CoilEasy Technologies Ltd to bring their US and China-patented technology to market. They also gained support for two consecutive years from the Hong Kong government's Technology Start-up Support Scheme for Universities (TSSSU).

CoilEasy is now working with major companies in Mainland China and the US to turn its technologies into products. The company's US collaborator is GlobalFoundries, which is among the largest semiconductor manufacturers in the world. Its Chinese industry partner Mornsun Guangzhou Science & Technology, located in Guangdong Province, is one of the largest power supply module vendors in China, with a worldwide distribution network. Earlier this year, CoilEasy completed its seed round for funding, receiving positive feedback from both investors and market.

For manufacturers, the advances are expected to add just four post-CMOS (fabrication) lithographic steps among the hundreds of other regular steps in the process of integrated chip production, making the power management improvements straightforward to incorporate and cost effective to implement.



HKUST's Embedded Solenoid Inductor Design improves inductor efficiency by 6%, compared with current solutions that struggle to attain 1% improvement. It also uses an area 5.5 times smaller than that of the conventional "on-chip" design.

The HKUST researchers' key innovation lies in the novel structure of the inductor, designed in a way to lodge the coil structure of the inductor within the silicon wafer substrate. This has provided a robust base for the component while keeping the essential smoothness of the chip surface, improving magnetic film performance, and reducing resistance and hence power loss.

WHERE AM I?

Step by step, turn by turn, the app-based pathfinder can point the way to where you want to go in an unfamiliar building

Getting lost in an airport, shopping center, or hospital will no longer be an excuse for lateness soon, with the arrival of smart mobility app "Wherami". This indoor localization technology, developed by computer scientist Prof Gary Chan, markedly improves accuracy in navigating large buildings, telling people on the move inside where they are and taking them to where they want to go.

Drawing on his expertise in algorithmic and optimization techniques, Prof Chan's navigational software works by combining Wi-Fi with other signals available from a mobile phone, including the geomagnetic field and motion sensor readings. In this way, the software can infer position to a much greater level of accuracy, with an average location error of less than 2.5 meters. This is three times more precise than conventional approaches.

Download the app, and the system simultaneously localizes users and calibrates the sensors. It does so by fusing different signals, rather than using a single source. It also employs an algorithm, devised by Prof Chan and his researchers, that optimizes user location based on the multiple signal readings while effectively mitigating the signal noises.

Prof Chan and his research team spent around four years researching and developing the first-generation app, which is now being deployed in major Hong Kong shopping malls including Harbour City, YOHO Mall and MOKO, as well as the Hong Kong Children's Hospital. It has been licensed to Compathnion, a company co-founded by Prof Chan and his team members.

> "It is rewarding to see how our research results and technology transfer have introduced novel smart city services which impact our lives"
>
> PROF GARY CHAN
> Professor of Computer Science and Engineering

Where Are They?

Prof Chan is now undertaking further leading-edge research on people sensing by answering the question "Where are they?" To do this, his team is developing cost-effective Internet-of-Things (IoT) sensors to detect people's movement through signal changes, hence finding people's locations. The system has multiple smart city applications, for example, analyzing and managing crowd flows, and tracking hospital patients and indoor assets.

The multi-award winning technology received a Silver Medal at the 2018 International Exhibition of Inventions of Geneva, among others, and is now being commercialized by Smart Sensing, a separate HKUST start-up, co-founded by Prof Chan in 2018. The company focuses on assisting mall and shop owners to better understand customer traffic, leading to more informed decision-making on business operations.

Prof Chan, a holder of numerous patents, has a strong track record of overcoming Wi-Fi-related challenges. Among his earlier contributions is the development of Lavinet, which eliminates Wi-Fi blind spots by extending coverage through an adaptive multi-hop technology. The system has been deployed at a leading container terminal in Hong Kong.

FACTS AT A GLANCE

Established

October 1991

Academic Departments and Divisions

22

Faculty Members (Regular)

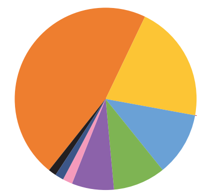
657#^

as at April 2019

^ includes teaching-track faculty

Faculty Profile

Academics come from **36** countries/regions.



- Mainland China - 34%
- Hong Kong - 27%
- North America - 18%
- Asia (excl. Mainland China & HK) - 10%
- Europe - 8%
- Australia & New Zealand - 2%
- Africa & Others - <1%
- Central & South America - <1%

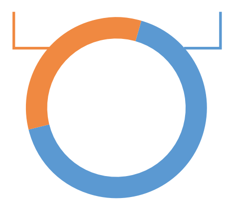
Student Enrollment

16,054*

HKUST has the highest percentage of international undergraduate students (9.6%) among all local universities in 2018-19.

Postgraduate 5,906*

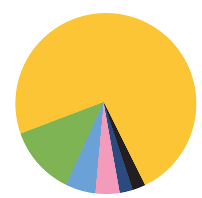
Undergraduate 10,148*



* as at September 2019

International Postgraduate Students

Students come from **70** countries/regions.



- Asia (excl. Mainland China) - 66%
- Europe - 18%
- North America - 8%
- Africa - 4%
- Central & South America - 2%
- Australia & New Zealand - 2%

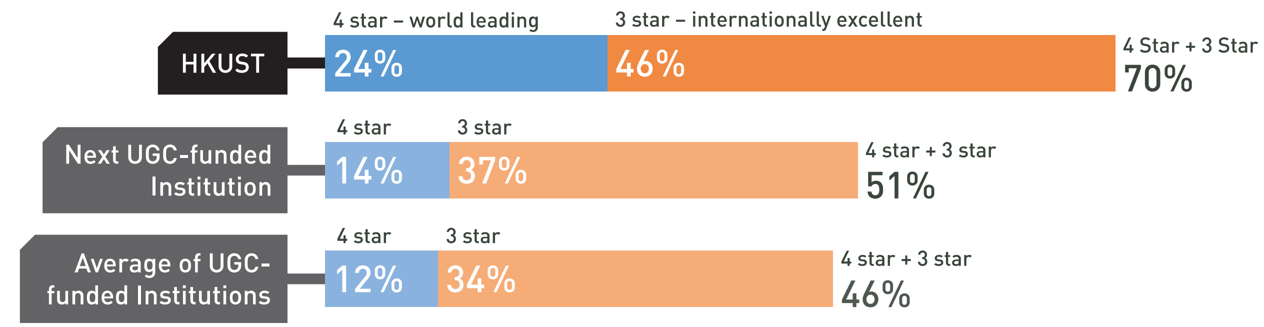
UNIVERSITY RANKINGS+

+ as at September 2019

HKUST		
#1	World's Top 350 Young Universities	Times Higher Education Young University Rankings 2019
#2	World's Top 150 Universities Under 50	QS Top 50 Under 50 2020
#3	Asia's Top 400+ Universities	Times Higher Education Asia University Rankings 2019
#7	Asia's Top 500 Universities	QS Asia University Rankings 2019
#32	World's Top 1000 Universities	QS World University Rankings 2020
#47	World's Top 1300+ Universities	Times Higher Education World University Rankings 2020
School of Science		
#22	World's Top 600 Universities in Chemistry (No. 1 in Hong Kong)	QS World University Rankings by Subject 2019
#23	World's Top 400 Universities in Materials Science (No. 1 in Hong Kong)	QS World University Rankings by Subject 2019
School of Engineering		
#18	World's Top 500 Universities in Engineering and Technology (No. 2 in Greater China)	QS World University Rankings by Subject 2019
#23	World's Top 800+ Universities in Engineering and Technology (No. 1 in Hong Kong)	Times Higher Education World University Rankings 2019
#22	World's Top 500 Universities in Electrical and Electronic Engineering (No. 1 in Hong Kong)	QS World University Rankings by Subject 2019
School of Business and Management		
#1	Global EMBA Ranking – Kellogg-HKUST EMBA Program	Financial Times Executive MBA Rankings 2018
#27	Top 100 Business School Research Rankings (No. 1 in Asia)	University of Texas at Dallas (UTD) Top Business School Research Rankings 2014-2018
#16	World's Top 500 Universities in Business and Management Studies (No. 2 in Asia)	QS World University Rankings by Subject 2019
#18	World's Top 300 Universities in Accounting and Finance (No. 2 in Asia)	QS World University Rankings by Subject 2019
School of Humanities and Social Science		
#26	World's Top 500 Universities in Social Sciences and Management (No. 3 in Greater China)	QS World University Rankings by Subject 2019

RESEARCH ASSESSMENT EXERCISE (RAE)

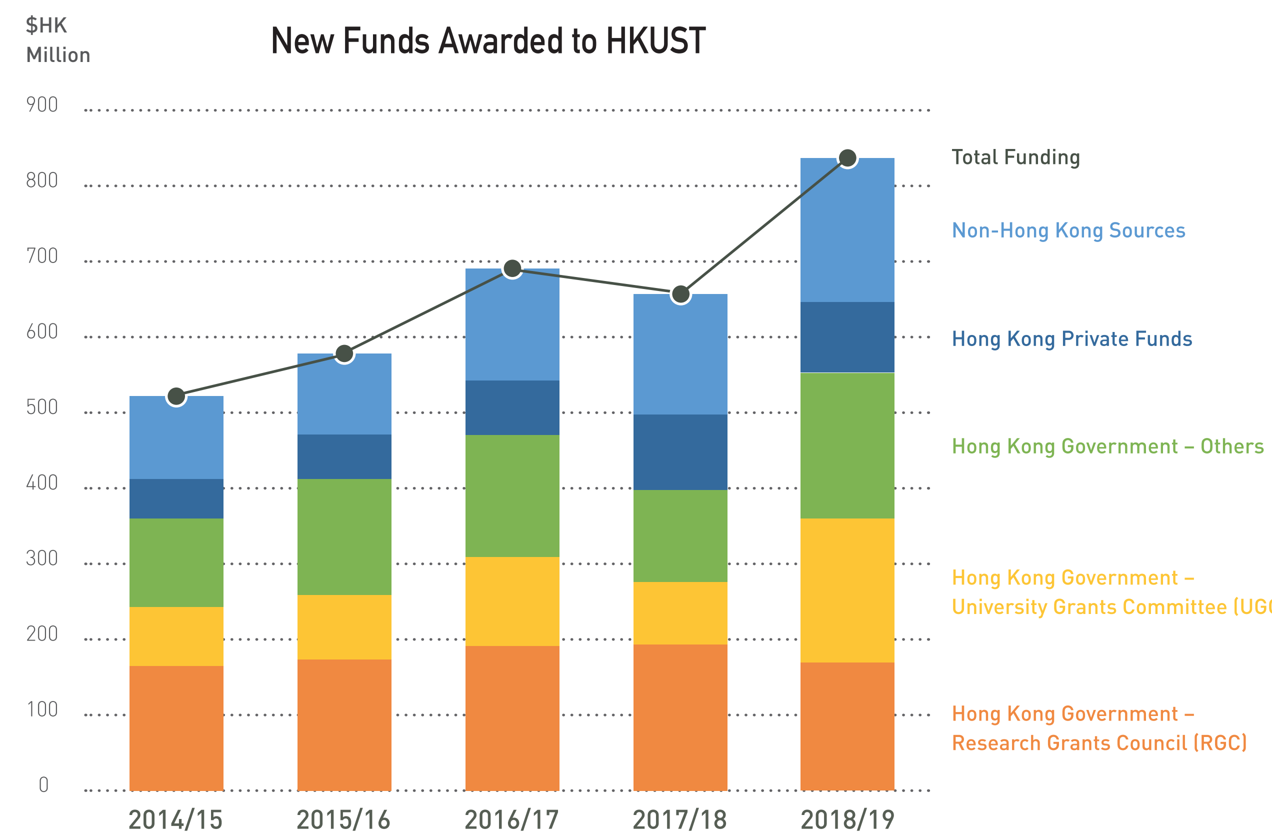
HKUST topped the institutional assessment with a remarkable 70% of its submissions (13 out of 19 cost centers or academic units) rated either "world leading" (4 star) or "internationally excellent" (3 star), according to the most recent RAE (2014), conducted by the University Grants Committee (UGC) in Hong Kong.



More information on RAE 2014 is available at http://www.ugc.edu.hk/eng/ugc/activity/research/rae/rae2014.html.

EXTERNAL COMPETITIVE RESEARCH FUNDING

(excluding Government block grants)



General Research Fund (GRF)

Consistently achieved the **highest success rate (47% in 2018/19)** among all local universities.

Early Career Scheme (ECS)

Achieved the **second highest success rate (59% in 2018/19)** among all local universities.

Croucher Innovation Awards

Awarded **three out of nine** Croucher Innovation Awards in the past three years.

Hong Kong PhD Fellowship Scheme (HKPFS)

Recruited **the highest number** of HKPFS awardees, cumulatively, among local universities in the past 10 years (2010/11 – 2019/20).
More than 10% of our current PhD students are recipients of this prestigious Fellowship.

LARGE-SCALE COMPETITIVE RESEARCH PROGRAMS (CURRENT)

The **Areas of Excellence Scheme (AoE), Theme-based Research Scheme (TRS) and Collaborative Research Fund (CRF)** are large-scale group research grants awarded by Hong Kong Research Grants Council. The grants support internationally recognized research expertise in order to develop areas of excellence that can help maintain and enhance Hong Kong's overall development. They also support research areas of strategic importance for Hong Kong's long-term development, and encourage out-of-the-box cross-disciplinary projects. **State Key Laboratory** and Hong Kong Branch of **Chinese National Engineering Research Center** are national research laboratories approved by the Ministry of Science and Technology, China.

State Key Laboratory

- State Key Laboratory of Advanced Displays and Optoelectronics Technologies
  PROF CHING WAN TANG
- State Key Laboratory of Molecular Neuroscience
  PROF NANCY IP

Hong Kong Branch of Chinese National Engineering Research Center

- Hong Kong Branch of Chinese National Engineering Research Center for Control and Treatment of Heavy Metal Pollution
  PROF GUANGHAO CHEN
- Hong Kong Branch of Chinese National Engineering Research Center for Tissue Restoration and Reconstruction
  PROF BENZHONG TANG

Areas of Excellence Scheme

- Centre for Slope Safety
  PROF CHARLES NG
- Cellular Mechanisms of Synaptic Functions and Plasticity in Health and Neurodegenerative Diseases
  PROF NANCY IP
- Mechanistic Basis of Synaptic Development, Signalling and Neuro-disorders
  PROF MINGJIE ZHANG
- Novel Wave Functional Materials for Manipulating Light and Sound
  PROF CHE TING CHAN

Theme-based Research Scheme

- A Stem Cell Approach to Dissect the Molecular Basis of Neurodegenerative Diseases
  PROF NANCY IP
- Contributing to the Development of Hong Kong into a Global Fintech Hub
  PROF KAR YAN TAM
- Creation of Rechargeable Electron-fuels for Stationary Power Supplies and Electric Vehicles
  PROF TIANSHOU ZHAO
- Diagnosis and Prognosis of Intensifying Eutrophication, Hypoxia and the Ecosystem Consequences around Hong Kong Waters: Coupled Physical-biogeochemical-pollution Studies
  PROF JIANPING GAN
- Smart Urban Water Supply Systems (Smart UWSS)
  PROF MOHAMED GHIDAOUI
- Understanding Debris Flow Mechanisms and Mitigating Risks for a Sustainable Hong Kong
  PROF CHARLES NG

Collaborative Research Fund

Group Research Projects

- Non-Hermitian Systems in Optics and Acoustics
  PROF JENSEN LI
- A Human-Powered Machine Learning System
  PROF LEI CHEN
- Development of Infrared-mediated Single Cell-labeling and Study of Non-HSC-derived T Cells in Zebrafish
  PROF ZILONG WEN
- Reconstitution of Postsynaptic Densities of Excitatory Synapses
  PROF MINGJIE ZHANG
- Quantum State Manipulation of Ultracold Atoms in Optical Lattices
  PROF SHENGWANG DU
- Aggregation-Induced Emission (AIE): Development of New AIE Systems and Exploration of Their Biomedical Applications
  PROF BENZHONG TANG
- Community and Population Aging in Hong Kong: An Extension of the Hong Kong Panel Study of Social Dynamics (HKPSSD)
  PROF XIAOGANG WU
- Study of Topological Phases in Condensed Matter and Cold Atom Systems
  PROF KAM TUEN LAW
- Coping with Landslide Risks in Hong Kong under Extreme Storms: Storm Scenarios, Cascading Landslide Hazards and Multi-hazard Risk Assessment
  PROF LIMIN ZHANG
- From Molecular Dynamics to Systems Biology: A Multi-scale Approach Tightly Integrating Simulation and Experiment to Quantitatively Analyze the Transcription Accuracy of RNA Polymerase II
  PROF XUHUI HUANG

Equipment Projects

- An Integrated Multi-functional System of In-situ Transport Measurements and Atomic Scale Characterizations for Two-dimensional Materials
  PROF NIAN LIN
- A Modular Drum Centrifuge Facility for Research into Mountain and Estuary Hazard Mitigation and Environmental Protection
  PROF LIMIN ZHANG
- A Deep Reactive Ion Etching System for Nanosystem Fabrication
  PROF ANDREW POON
- A Platform for Measuring the Physical Properties of Quantum Materials
  PROF JIANNONG WANG

RESEARCH INFRASTRUCTURE

One of the distinctive features of HKUST's founding vision was to encourage interdisciplinary research from the University's earliest days. Recognizing the complexity of a globalized world and the cross-field challenges, such as climate change and sustainability, the University has made key infrastructural provisions to assist top minds in working together to build solutions.

RESEARCH INSTITUTES AND CENTERS

A centrally located Academic Building facilitates natural and frequent interaction among faculty members from different fields. The establishment of research institutes and centers, now numbering 9 and 33 respectively, fosters cooperation across traditional boundaries. Key research institutes are:

GREAT Smart Cities Institute

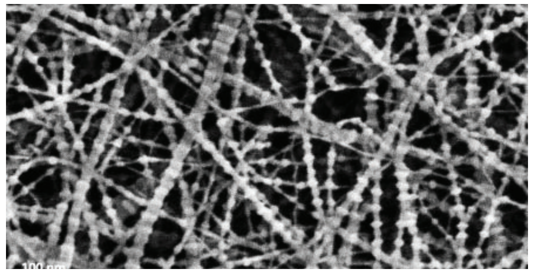
Institute for Emerging Market Studies

Big Data Institute

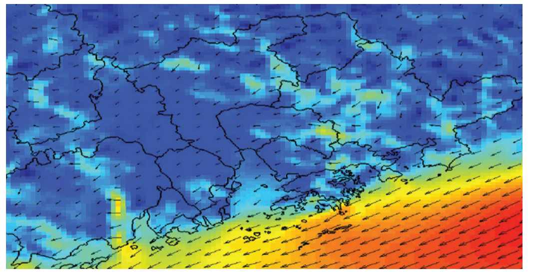
Biotechnology Research Institute

Energy Institute

Robotics Institute



William Mong Institute of Nano Science and Technology



Institute for the Environment

CENTRAL RESEARCH FACILITIES

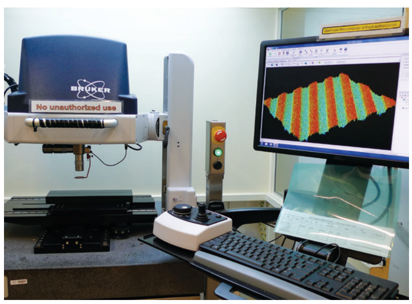
The Central Research Facilities are a pillar of the University's research infrastructure and play a vital and integral role in our multidisciplinary approach.

Advanced Engineering Materials Facility: houses leading research equipment to develop advanced engineering materials technology and its applications.

Animal and Plant Care Facility: humane care and husbandry, subject to rigorous HKUST-approved experimental protocols.

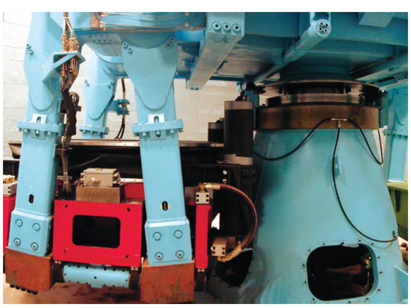
Biosciences Central Research Facility: provides cutting-edge communal equipment, training, and other activities to aid R&D in all areas of biological sciences.

CLP Power Wind/Wave Tunnel Facility: world-class experimental facility to test wind effects on structures and the environment.

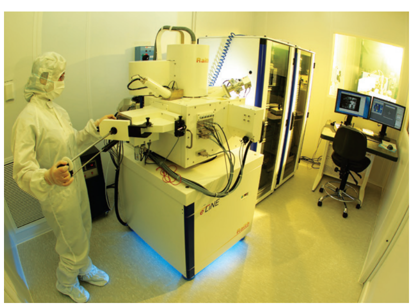


Design and Manufacturing Services Facility: offers unique services e.g. design and fabrication of sophisticated mechanical and electronic parts, nano measurements, CAE analysis, five-axis metrology, and reverse engineering.

Environmental Central Facility: offers analytical instruments for environmental research and supports field and modeling studies in atmospheric research.



Geotechnical Centrifuge Facility: physical modeling of engineering problems using the world's first in-flight 2D shaking table and a state-of-the-art four-axis robotic manipulator.



Materials Characterization and Preparation Facility: a core facility to serve research needs for the preparation, characterization, and analysis of various advanced materials.

Nanosystem Fabrication Facility: the first and only complete nanofabrication facility set up in a Hong Kong tertiary institution.

Design and Production by M&L www.mandl.asia

香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY