

2024

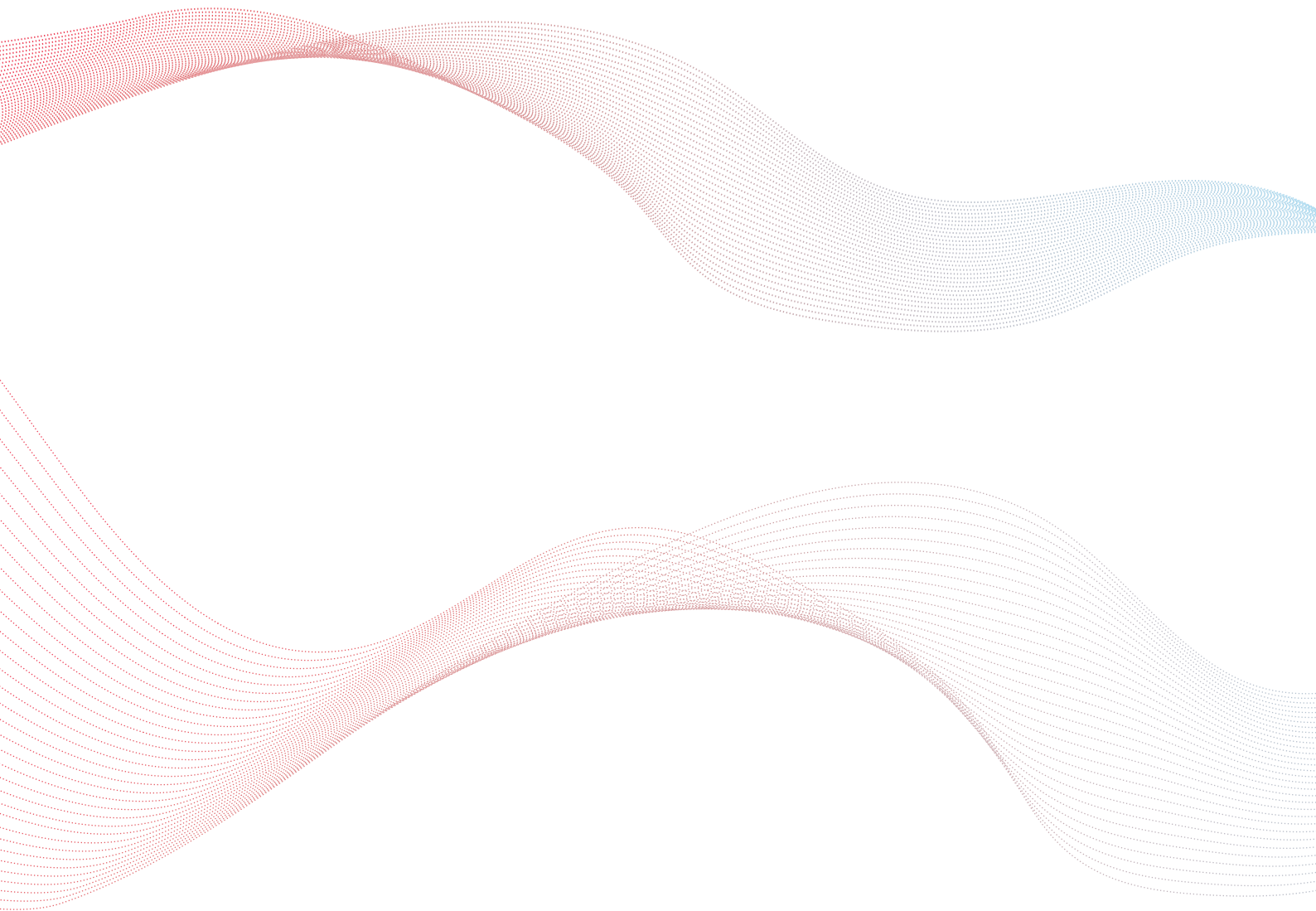
Hon Hai Research Institute
Yearbook

2024

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About Hon Hai Research Institute

The establishment of Hon Hai Research Institute marks a key milestone in Hon Hai Technology Group's strategic transformation toward the F3.0 era. The Institute comprises five research centers and one laboratory, each staffed by an average of 40 top-tier researchers dedicated to exploring cutting-edge technologies poised to shape the next three to seven years. Its mission is to strengthen Hon Hai's innovation in both technology and product development, advancing the company from a labor-intensive to a knowledge-intensive enterprise and enhancing the Group's core competencies under its 3+3 development strategy.

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Seeking Fundamental Solutions with Openness

Whenever I speak about the future of Hon Hai, I emphasize that we are transforming from a manufacturing company into a technology company. This is not a mere slogan but a vision we actively pursue. At the heart of this transformation is the Hon Hai Research Institute, the core engine driving this shift. Its mission is clear: to develop the Group's core technologies for the next three to seven years and to ensure that Hon Hai maintains its competitive edge in the waves of rapid technological advancement.

Since becoming President, one of my key reforms has been to clearly separate technology R&D from product R&D. In the past, long-term research was often constrained by short-term business goals. Today, we view it as an investment in the future, not a cost to be trimmed when expedient.

The Hon Hai Research Institute was founded with that vision in mind. Operating independently of business units and free from short-term profit pressures, the Institute focuses on emerging technologies with a three- to seven-year horizon. It serves as a bridge between cutting-edge academic research and the Group's extensive industrial applications, accelerating the transition from laboratory innovation to real-world implementation. This is more than just technology transfer; it is about the dissemination of knowledge and value. As I often ask of our teams, "The Institute exists to bridge academic research and industrial needs."

Our culture is built on one simple but powerful belief: "We are open, not closed." This spirit of openness defines who we are. We encourage our researchers to publish academic papers and file patents not only to protect our innovations but even more so to share them. Because only through sharing can the entire technology community advance together.

Openness and Collaboration: Expanding Research Horizons

In 2024, thanks to the dedicated efforts of our colleagues and partners, the Institute published 120 research papers and filed 30 patents. These achievements reflect our open and collaborative spirit, which may be expressed across three key areas:

1. Selfless sharing to promote mutual prosperity in the research community: We encourage our researchers to engage actively in academic exchange and share their work

with peers around the world. Through sharing, we make Hon Hai's research strengths visible to the world, enhance Taiwan's visibility in the global scientific community, and discover new directions for further advancement through dialogue.

2. Embracing fundamentals and championing scientific literacy: I often stress the importance of both popular science communication and first-principles thinking. If complex technology cannot be explained in simple, everyday language, it means we have yet to truly understand it. I encourage our senior researchers to write and communicate science in accessible ways by connecting abstract ideas to everyday life. This deepens understanding and cultivates true scientists who pursue fundamental insights, rather than mere technicians of science.

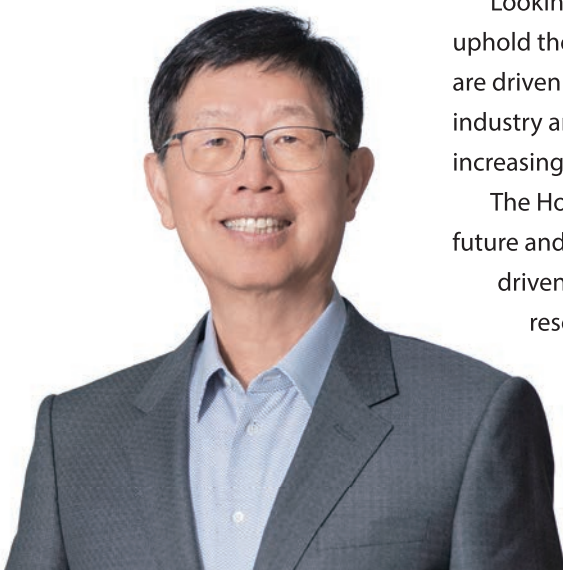
3. Broadening our vision to address global challenges: Our mission extends beyond Hon Hai; we strive to address the challenges facing Taiwan and the world. I encourage our teams to think globally, leverage Hon Hai's platform to engage with global industry leaders, identify the major issues that matter to industries worldwide, and transform them into bold, forward-looking research directions.

Over the past four years, the Institute has partnered with 46 academic institutions worldwide, taking on some of the toughest frontiers in technology. We have built a virtuous cycle that connects world-class problem statements with the strengths of basic research in universities. The Institute's breakthroughs, in turn, are channeled through the Group's CTO network, finding pathways to commercial application. This model, where academic research helps address the Institute's challenges and our innovations drive business applications, is now well established.

In recent years, the Institute has earned renewed respect and recognition from the global community. Our publications in AI, semiconductors, communications, quantum technology, and cybersecurity have been widely cited across disciplines, a testament to the dedication and excellence of every member of our team.

Looking ahead, the Hon Hai Research Institute will continue to uphold the values of sharing, collaboration, and mutual prosperity. We are driven not by short-term profit but by a long-term commitment to industry and society. I am confident that as the value we create becomes increasingly evident, recognition and reward will follow naturally.

The Hon Hai Research Institute represents both an investment in the future and a critical path to realizing our vision of a truly technology-driven company. We walk this path with confidence, conviction, and resolve.



Young Liu

President
Hon Hai Research Institute

The 3+3 Strategy: Planning Ahead for the Future

Hon Hai Research Institute (HHRI) is positioned distinctly from conventional corporate R&D departments. Our mandate is not short-term product development but long-term scientific exploration and frontier technology research. We focus on the next three to seven years, aligning our research with the Group's developmental goals.

We focus on foundational scientific and technical issues, channeling research outcomes toward commercial applications through our BD teams. The Group's technical divisions transform the research outcomes into applicable technologies, and our engineering teams apply these technologies to product development and manufacturing.

This structural division allows HHRI scientists to pursue advanced research with undivided focus, free from the pressures of product development timelines. Such a model is rare in Taiwan's corporate sector and remains distinctive even globally, as it requires long-term commitment and investment. Thanks to Chairman Young Liu's foresight, Hon Hai Research Institute was founded in 2020, offering scientists a research platform beyond academia and helping steer the Group's industrial innovation.

Rooted in Technology, Anchored for the Future

In November 2019, Hon Hai Technology Group formally outlined its strategic focus on three future industries: electric vehicles, digital health, and robotics, as well as three core technologies: artificial intelligence, semiconductors, and next-generation communications.

Notably, the research outcomes of Hon Hai Research Institute are not tied to specific products but serve as foundational technologies that underpin the Group's "3+3" industry strategy.

Within the Group, business units may develop different products, but the products share common underlying technologies. For instance, electric vehicles and robots both rely on communications support. As satellite communications evolve, connectivity is becoming more spatially dynamic, enhancing coverage and reducing latency, an area where Hon Hai excels. In AI, building on large language models and multimodal foundation models, generative AI is advancing at an unprecedented pace. It supports autonomous driving in EVs and is simultaneously enhancing the perception, reasoning, and mobility of humanoid robots, bringing them ever closer to artificial general

intelligence (AGI). Meanwhile, EV charging stations require specialized semiconductors that can withstand high temperatures, voltages, and frequencies. Through investment in compound semiconductor research, the HHRI is laying the groundwork for the performance demands of next-generation products.

These forward-looking researches provide strong technological backing for the Group's "3+3" strategy. Our role is like the basic bricks in a stack, and the business units use those bricks to build the products they envision.

Our ability to deepen frontier research and expand our impact is made possible by Chairman Liu's direct leadership. As President of Hon Hai Research Institute, he bridges communication gaps within the corporate hierarchy and meets with us regularly to shape research directions. He ensures that our work is tightly integrated with the Group's long-term development blueprint.

This approach reflects the Group's trust in its researchers, granting them the freedom to fully explore uncharted areas, as long as they contribute meaningfully to the Group's future. Many of these efforts reach well beyond current product needs, laying the groundwork for overcoming future technological bottlenecks and helping Hon Hai stay ahead in global competition.

Driven by Science, Boldly Exploring the Unknown

HHRI is supported by an international Advisory Committee composed of top-tier experts across disciplines. Their direct guidance offers invaluable insights and external perspectives, ensuring our research maintains both breakthrough potential and global relevance.

Thanks to our exceptional research environment and steadily growing academic reputation, the Institute continues to draw top talent from around the world. To advance technological innovation and facilitate knowledge transfer, we have also forged deep partnerships with leading institutions, including City University of Hong Kong and National Yang Ming Chiao Tung University.

Our mission is to plant the seeds of technological innovation today and lay the foundation for future breakthroughs. We are grounded in science and bold in exploring the unknown, transforming discoveries into core momentum for the Group's cross-industry development. In an era of intensifying global competition, we will continue to attract top talent and resources worldwide to help propel Taiwan to the forefront of the global technological stage.



A handwritten signature in black ink that reads "Wei Bin Lee".

Chief Executive Officer
Hon Hai Research Institute

Kai-Fu Lee

CEO of 01.AI and Chairman of Sinovation Ventures

The Real AI Opportunity: Not in Models, but in Agents and Applications

Artificial intelligence (AI) is advancing at an unprecedented pace. Foundation models, driven by reinforcement learning, have introduced a new growth paradigm for reasoning intelligence. Agents, once limited to answering questions and casual conversation, now wield multimodal capabilities: they process diverse data, make intelligent decisions, and, starting in 2025, usher in what I call the “Year One of Reasoning Agents.” With human collaboration, these agents will not only invent previously unimaginable formulas and medicines but also plan organizational goals and optimize operational strategies.

In 2025, open-source models have begun to surpass their closed-source counterparts. Many top-tier open projects now rival the best proprietary systems, driving broader affordability and laying a strong foundation for the rise of AI-first applications such as agents. By contrast, most leading U.S. AI companies still favor closed approaches, while China is advancing innovation through open-source platforms like DeepSeek and Alibaba’s Qwen. I believe open source will ultimately prevail, ushering in a new era of technological democratization.

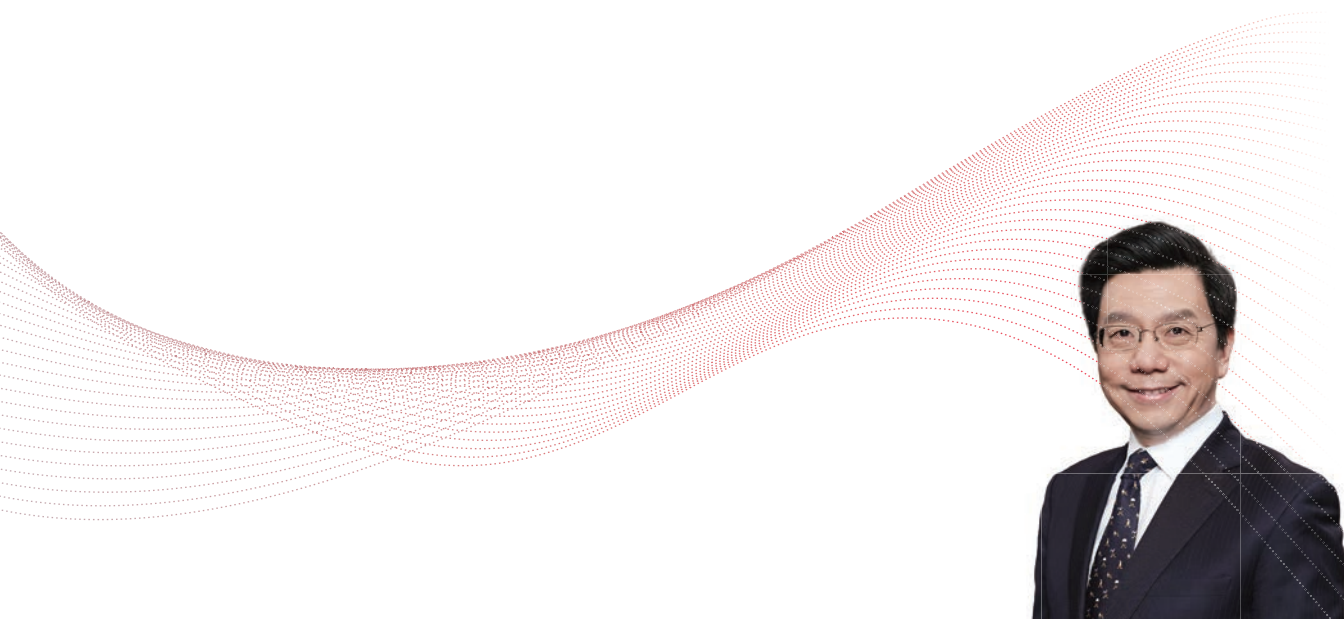
This shows how the open-source ecosystem advances through sharing and

collaboration, as opposed to the opaque development processes behind closed-source models. A few thousand brilliant minds in a closed system cannot rival the iterative power of tens of millions in the global intelligence community. Notably, the vanguard of open-source innovation has already shifted from the U.S. to China, a trend that merits close attention.

Global development of foundational models has now converged around eight major players: four closed-source and one open-source in the U.S., and one closed-source and two open-source in China. These massive underlying models are moving toward commoditization. On their own, they are unlikely to yield substantial commercial value, unless the market consolidates to a single dominant provider, which I find unlikely. The real opportunities will emerge above these models, in the application layer.

The year 2025 will be a breakout year for agents and applications. Take Cursor, a U.S.-based company behind an AI code editor. Its annual recurring revenue (ARR) has already reached US\$500 million. Many other agent and application companies are also seeing ARR in the US\$50 to US\$100 million range.

As AI penetrates deeper into physical



industries such as manufacturing, Hon Hai, as a global manufacturing leader, possesses vast reserves of data and domain expertise that are key to building intelligent applications. To harness this wave, I recommend that Hon Hai Research Institute adopt a simple principle: the more data, the greater the compute, the

better the results. By leveraging generative AI and agents, deeply excavating industry-specific needs, and proactively asking “What will tomorrow require?”, Hon Hai can generate distinctive breakthroughs and secure its leadership in the coming AI era.



AI agents with multimodal capabilities can not only innovate but also plan and optimize organizational goals and strategies.

M. C. Frank Chang

Distinguished Professor

Wintek Chair in Electrical Engineering, UCLA

Heterogeneous Integration: Key to Developing Fully Optoelectronic SoCs



In optoelectronics and semiconductors, one of the most compelling emerging trends in 2025 is the development of a full-spectrum System-on-Chip from RF-to-Optics. Achieving this ambitious goal, however, will require driving heterogeneous integration down to the device junction level.

Hon Hai Research Institute has begun research into heterojunction material generation. Current efforts remain largely at the device level, such as peeling silicon layers and bonding them onto silicon carbide substrates. By contrast, growing gallium nitride (GaN) directly on large silicon wafers offers superior potential for scalability and deployment, including the possibility of heterojunction growth across an entire wafer. This is the direction we hope HHRI will actively pursue in the near future.

The central challenge today lies in the direct formation of heterojunction materials on silicon substrates. Since silicon itself does not emit light, achieving true optoelectronic integration requires integrating light-emitting gallium nitride (GaN) with silicon-based electronic devices. This involves complex epitaxial growth techniques, and researchers and industry players worldwide are experimenting with various approaches to overcome the technical barriers.

Precision remains a major challenge in

photonic device engineering. Achieving tight optical alignment between transmitters and receivers at the microscopic scale, while enabling large-scale integration, is a formidable technical hurdle. It is also one of the key reasons why the cost of photonic integrated circuits remains high. A breakthrough in this area could significantly reduce the production costs of optoelectronic system chips.

Since its founding in 2020, Hon Hai Research Institute has produced world-class publications and forged international collaborations. Yet what matters even more is the courage to ask not only how to do things well, but why we do them in the first place. We strive for quantum leaps, not merely doing things well but doing the right things, even if it means taking on challenges once deemed impossible. Only through this mindset can we create technologies that are unprecedented, uniquely competitive, and form the unique core strengths of Hon Hai Technology Group.

Ching-Ray Chang

Distinguished Professor, NTU Department of Physics

Fusion of Quantum and Supercomputing: The Future of Computing



Quantum and classical computing each offer distinct advantages. Looking ahead, the fusion of quantum computing and supercomputing promises complementary computational power that can significantly enhance the efficiency of solving complex problems. This is a trend worth watching closely.

In recent years, the Quantum Computing Research Center has published extensively in top-tier international journals and conferences, positioning its research among the global leaders in the field. It has also actively pursued diverse international collaborations, rapidly elevating the reputation of Hon Hai Research Institute in quantum research. Meanwhile, the Trapped-Ion Quantum Computing Laboratory has established a low-noise, low-vibration environment and successfully trapped ion arrays. With key equipment expected to arrive within the next year, the lab aims to demonstrate control of 10 qubits by late 2025 or early 2026 and to launch a 5- to 10-qubit open-source, programmable ion-trap quantum computer in 2027.

In developing quantum computers, the sheer number of qubits is only part of the equation. Even more critical is the ability to precisely control them and maintain sufficient computational fidelity to enable reliable operations. Achieving this requires sustained efforts and a well-defined development roadmap.

The timeline for quantum computing to reach maturity remains hotly debated. In January 2025,

Nvidia CEO Jensen Huang suggested that the technology may require at least another 20 years to enter a truly mature phase. However, at the Nvidia GTC conference in June, he remarked that the field was approaching a critical turning point, with the potential to tackle significant global challenges in the coming years.

In my view, quantum technology may take two decades or more to reach mainstream adoption. However, for users in specialized domains, major breakthroughs could emerge within three to five years. Some teams have already reported achieving logical 50 qubits, and if 100 qubits are reached, computational power could surpass that of today's classical computers.

Looking ahead, I recommend that the Quantum Computing Research Center strengthen collaboration with Hon Hai Technology Group's commercial and manufacturing divisions, ensuring that research outcomes are translated into practical applications. Meanwhile, the Trapped-Ion Quantum Computing Laboratory should continue to adapt its objectives in line with the latest quantum developments and establish a clear development roadmap, first by strengthening internal capabilities, then by accelerating progress toward international standards. Ultimately, I hope the achievements of both the Quantum Computing Research Center and the Trapped-Ion Laboratory will help Hon Hai Technology Group secure a first-mover advantage in the era of quantum-supercomputing fusion.

Tsung-Cheng Wu

Distinguished Professor, Department of Information Management,
National Taiwan University of Science and Technology

Harnessing Collective Intelligence to Advance the Value of AI Cybersecurity



As artificial intelligence (AI), cloud computing, and the Internet of Things (IoT) continue to advance and become mainstream, cybersecurity risks in enterprise operations and cross-domain applications are also on the rise. In this context, safeguarding trade secrets and sensitive data has become an even more pressing concern.

While AI can significantly enhance product innovation and strengthen competitiveness, it can also be a double-edged sword in cybersecurity. Generative AI, designed to harness collective intelligence, carries the risk of inadvertently exposing trade secrets through improper use and raises critical concerns about the trustworthiness, reliability, and usability of both raw and derived data. In response, governments and major enterprises worldwide are actively advancing the concept and local implementation of Sovereign AI.

Sovereign AI operates much like a private cloud. It spreads operational knowledge across departments, facilitating paradigm shifts without exposing critical information to competitors. At the same time, the cross-domain nature of ICT systems is blurring traditional boundaries, making hidden risks even harder to detect and control.

With Sovereign AI, enterprises retain control over their own algorithms and training datasets. This autonomy allows them to

identify and patch vulnerabilities in their ICT systems, thereby broadening and deepening cybersecurity defenses.

The Hon Hai Research Institute is tasked with advancing emerging technologies and driving innovation for the Hon Hai Technology Group. In recent years, it has demonstrated strong research capabilities and tangible results in cross-domain AI cybersecurity. I hope the Institute's continued commitment, through its own research and through its long-standing collaborations with world-leading research institutions, will help disseminate knowledge across Taiwan's industries and universities, while highlighting the value of Taiwan's high-tech sector and talent on the global stage.



Deploying sovereign AI enhances both the depth and breadth of cybersecurity defenses.

Wanjiun Liao

Executive Vice President, National Taiwan University

Kickstarting the 6G Revolution with AI-RAN Integration



Traditional mobile networks are divided into two main components: the Radio Access Network (RAN) and the Core Network. The RAN manages direct connections between devices and base stations, allocating resources to optimize network utilization. The Core Network, by contrast, handles functions less directly tied to connectivity, such as identity authentication, billing, and value-added services.

The core of future 6G is AI Native, where AI enhances functionality across all layers of the network during the transmission process. This integration can be categorized into three main approaches: AI for RAN, AI on RAN, and AI and RAN.

AI for RAN leverages AI to improve wireless connectivity and optimize resource allocation. AI on RAN refers to deploying AI applications directly on network nodes, such as base stations, enabling them to run AI workloads or process parameters for small machine learning models on devices. As for AI and RAN, it explores the possibility of transforming base stations into edge-computing nodes, a concept currently actively discussed within the industry.

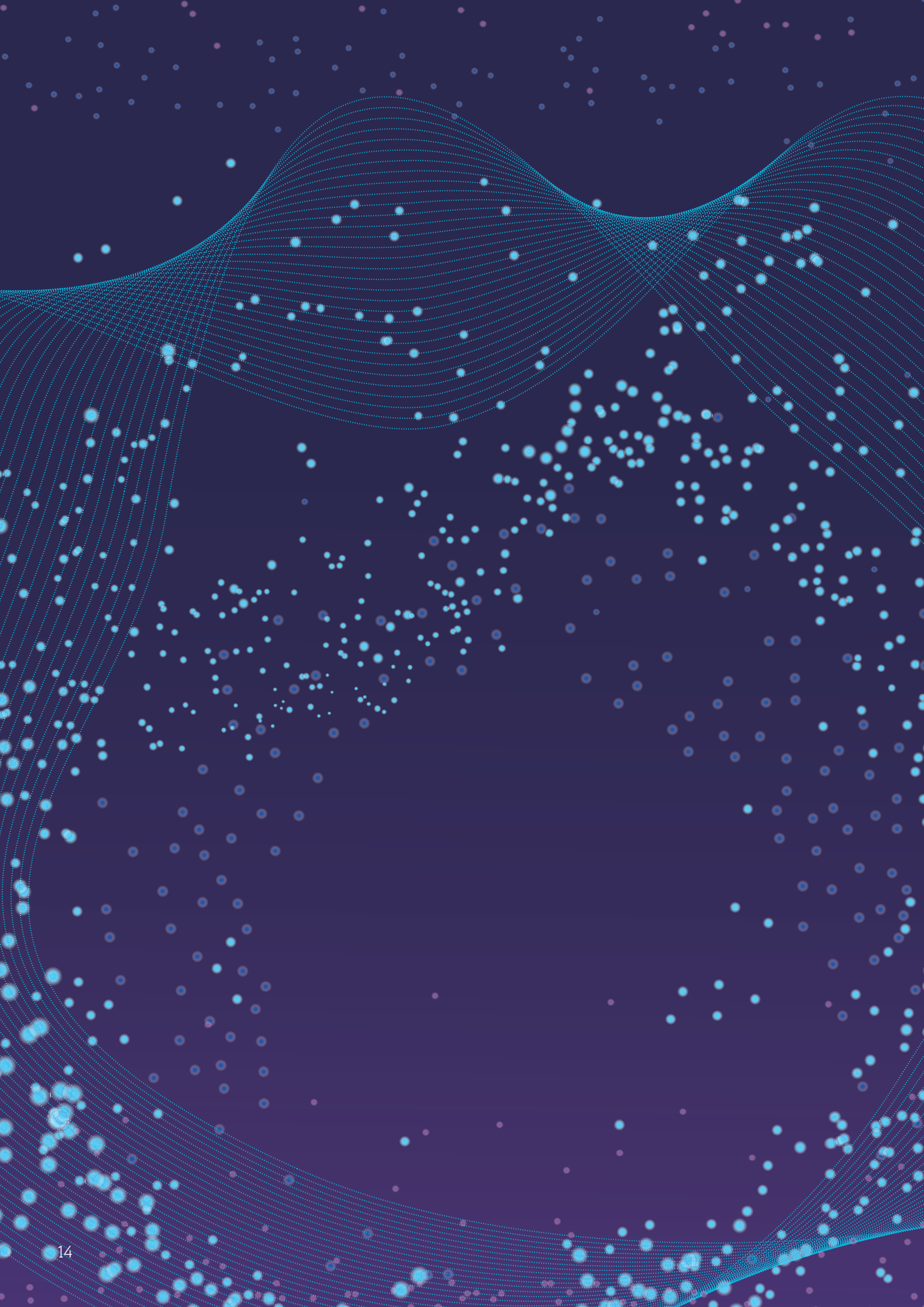
As more communication functions become software-defined and modular, capable of running on GPUs and CPUs, their operational model increasingly resembles that of AI. In the future, RAN will no longer be a rigidly defined network unit but rather a platform tightly

integrated with AI computing resources, capable of processing both communication and AI-related tasks.

In 2025, several industry leaders have already demonstrated AI and RAN test platforms, signaling the emergence of AI and RAN as a critical trend in networking. As AI models become more powerful, they not only improve communication technologies but also reshape how communication systems themselves are designed. This two-way interplay between AI and communications is set to become a key driver of 6G development.

Moreover, satellite communications will play a pivotal role in 6G development, particularly through the deployment of Low Earth Orbit (LEO) satellites. These satellites can cover roughly 80% of Earth that remains beyond terrestrial network coverage. Seamlessly integrating LEO satellites with existing mobile technologies will enable smartphones to connect directly via satellite, with the satellites effectively functioning as base stations. This transformation opens up significant commercial potential.

Hon Hai Research Institute's Next-generation Communications Research Center has successfully launched satellites into orbit and ensured their stable operation. Broadening LEO satellite development to integrate with AI and 6G represents a pragmatic and promising path for the industry.





Technology Frontiers

Amid a rapidly evolving global technological landscape, Hon Hai Research Institute brings together top research talent. Five research centers and one laboratory are strategically positioned in critical fields, driving the development and application of cutting-edge technologies, powering the Group's technological engine, and shaping the future of the industry.

Artificial Intelligence Research Center

Award-Winning Trajectory Prediction Models Powering Smarter Autonomous Driving

Have you ever wondered how an autonomous vehicle “thinks” as it manages to make precise turns and avoid pedestrians at a busy intersection? Behind every decision is a rapid sequence of high-speed computations: perceiving the environment, predicting the movements of nearby vehicles, and planning the safest route forward. All these are driven by exceptionally precise AI models.

The Three Pillars of Autonomous Driving

To understand how self-driving cars “think,” it is important to grasp three core technologies:

1. Perception: Enables the vehicle to “see” and accurately interpret its surroundings, including vehicles, pedestrians, road markings, traffic signals, and all static and dynamic objects. Perception is the foundation of autonomy; any error at this stage can invalidate all subsequent decisions.

2. Trajectory Prediction: Anticipates the future movements of nearby objects such as

vehicles and pedestrians. For example, if a nearby car suddenly accelerates or signals a lane change, the system must predict its most likely path.

3. Motion Planning: Uses perception and trajectory prediction to determine the vehicle’s safest course. For example, if the system predicts another vehicle merging ahead, it may choose to slow down or change lanes to avoid a collision.

Global Recognition with Two First-Place Wins

Building on its expertise in core autonomous driving technologies, the Hon Hai Artificial Intelligence Research Center (AI Center) gained global recognition in 2024 at the prestigious IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), one of the world’s leading AI conferences. In the trajectory prediction challenge, which focused on the second stage of autonomous driving, the Center earned two first-place finishes and one second-place.



The Artificial Intelligence Research Center develops real-time applications to enhance the safety and reliability of autonomous driving systems.

One of the first-place finishes came from the Argoverse 2 Motion Forecasting Challenge, hosted by Argo AI through its open-source dataset and research platform, Argoverse. Designed as a venue for competition and collaboration, Argoverse accelerates the development and deployment of autonomous

driving technologies.

In fact, the AI Center had earned recognition in the 2023 Argoverse 2 Challenge for its QCNet model, designed for real-time use in dynamic traffic environments. QCNet can process large volumes of vehicle, pedestrian, and complex traffic scenarios

Quick Reference

Patch-wise Attention Technique

A technique that divides input data into small patches and uses attention mechanisms to selectively analyze the most relevant regions. Commonly used in traffic simulation and other dynamic environments, it improves computational efficiency by focusing on salient features, much like how humans selectively attend to critical elements in complex driving scenarios.



Integrating electric vehicles with AI technologies, autonomous driving is key to unlocking the value and innovation potential of EVs.

without increasing computational complexity, thus substantially improving the safety and reliability of autonomous driving systems.

Building on that success, the AI Center introduced Lite-QCNet in 2024, a model that applied attention-based patch-wise processing for temporal abstraction and a K-nearest neighbor (K-NN) local attention algorithm to capture spatial interactions. This design enables Lite-QCNet to maintain accuracy while significantly reducing computational load and model size. It achieved state-of-the-art performance on Argoverse 2 benchmarks, demonstrating outstanding efficiency in multi-agent motion

prediction.

Another first-place win came from the Waymo Motion Prediction Challenge, hosted by Waymo, Google's autonomous driving subsidiary. Focused on trajectory prediction in real-world driving scenarios, the competition aimed to advance autonomous driving technologies and to provide a platform for researchers to showcase their work and engage in technical exchange.

The challenge required teams to predict the future trajectories of each dynamic agent, such as vehicles and pedestrians, within simulated driving scenarios. A key requirement was that predictions must account for multiple

plausible outcomes rather than focusing solely on the single most likely path. For instance, a vehicle might continue straight or switch lanes. The ability to model such multi-modal possibilities is essential for safe and reliable motion planning in autonomous systems.

Precision Computation Driving the Future of Autonomy

Following the AI Center's two first-place finishes, Director Yung-Hui Li emphasized that the success was not the result of any single factor but from strong performance in different areas, including data processing, model design, and multi-model integration.

He explained that even when working from the same dataset, variations in data cleaning, statistical analysis, and preprocessing could result in substantial performance differences. Likewise, while the Transformer architecture has become mainstream, each team customizes its structure, modules, and parameters differently, much like skilled craftsmen using similar tools to create unique works.

The two first-place finishes marked a significant step forward in autonomous driving technology, Lee explained. They demonstrated improved accuracy in

predicting the intentions of surrounding vehicles, which enhanced decision-making in self-driving systems. In addition, they contributed to more realistic vehicle behavior within simulation environments, which in turn supported the training of smarter autonomous driving models.

Notably, these research milestones closely align with Hon Hai Technology Group's "3+3+3" transformation strategy, in which electric vehicles play a central role. As Director Li noted, autonomous driving is the critical convergence point between EVs and AI, making it essential to unlocking the full value and innovation potential of electric mobility.

Hon Hai Technology Group is actively investing in the independent training of foundational AI models in anticipation of the transformative shifts in the AI landscape. Its generative AI strategy centers on building three core platforms for smart manufacturing, smart EVs, and smart cities.

According to Director Li, the Fox Brain large language model, developed in-house by the Hon Hai Research Institute, will serve as the core foundational model powering all three platforms. It will also be integrated into the Group's autonomous driving technology, making it an indispensable part of Hon Hai's overall strategy.

Quick Reference

K-NN Local Attention Algorithm

The model does not treat all agents equally before making predictions. Instead, it selects the K nearest neighbors for interaction modeling, then applies attention to assess their relative influence. This allows the model to assign differentiated weights and focus on the agents most likely to affect decision-making.



Semiconductor Research Center

From Materials to Optics: Building the Core Foundations of AI Applications

Faced with the challenges brought about by high-speed computing and data explosion in the AI era, Dr. Hao-Chung Kuo, Director of the Semiconductor Research Center, identifies three critical technologies as essential, energy-efficient enablers for AI data centers: compound semiconductors, silicon photonics, and nanophotonics. From breakthrough research in gallium oxide (Ga_2O_3) semiconductors and high-speed silicon photonic chips to innovations in depth sensing and spatial computing, Taiwan continues to showcase its strength in advanced semiconductor development and intelligent sensing technologies.

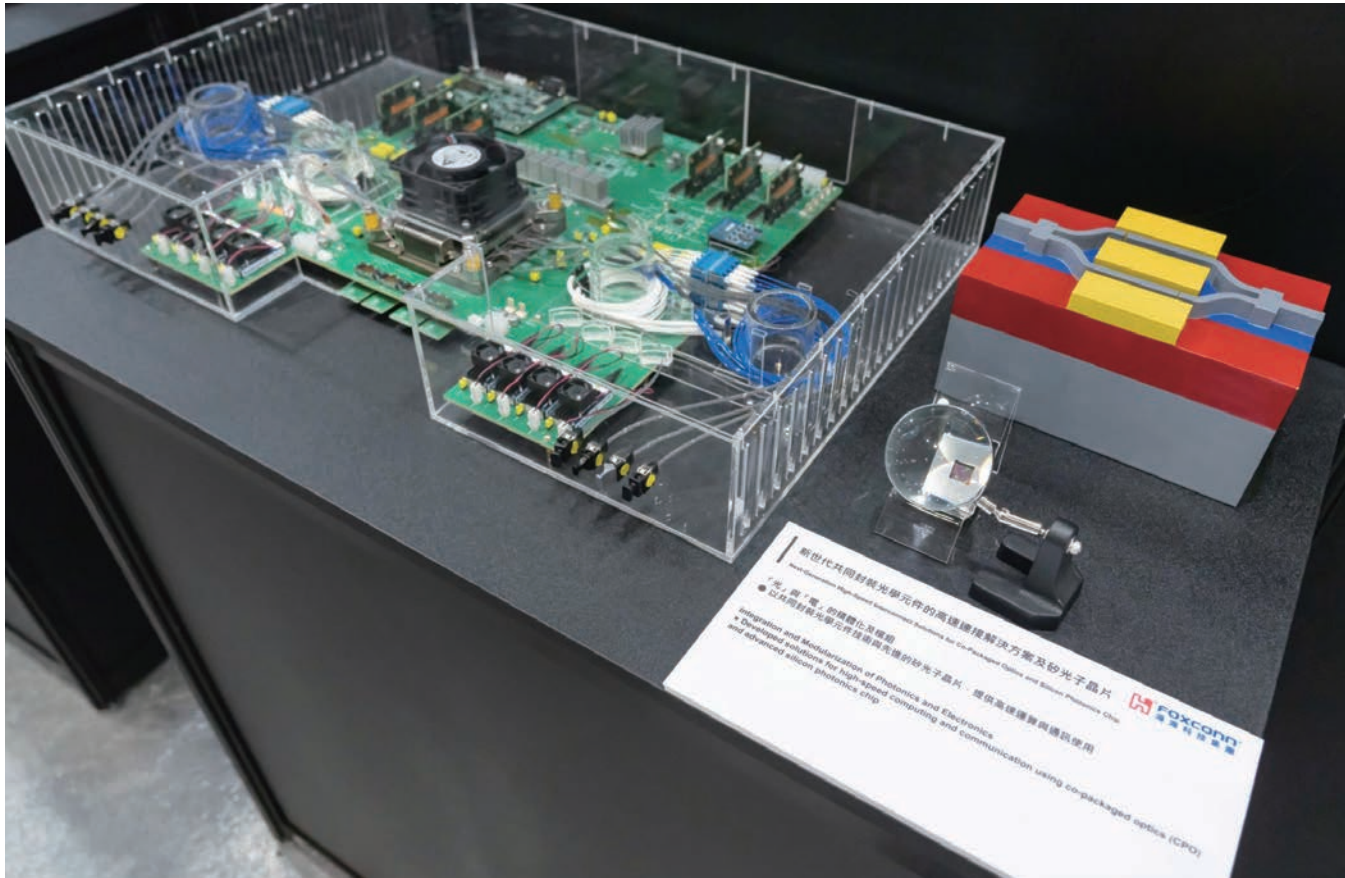
Fourth-Generation Compound Semiconductors

Compared to conventional silicon, compound semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) feature significantly wider bandgaps, almost three times that of silicon. This enables them to withstand higher voltages and temperatures,

making them ideal for high-power electronics. Their wider bandgap also means electrons are less prone to scattering, which dramatically reduces leakage, enhances safety, and improves energy efficiency. Lower leakage translates to reduced energy loss, allowing for higher voltage and current output with less heat. Overall, power consumption can be cut by over 75%, and heat dissipation is up to three times more efficient than silicon.

Compound semiconductors were first used in electric vehicles, with Tesla pioneering their adoption as early as 2017. With the rapid development of AI, green energy, robotics, and drones, demand for applications that prioritize energy efficiency and extended battery life has surged, and compound semiconductors have thus become essential. In particular, integrating them into LLC converter circuits in AI servers can yield conversion efficiencies of up to 97 to 98%.

In August 2024, the Semiconductor Research Center, in collaboration with National Yang Ming Chiao Tung University (NYCU), achieved a major breakthrough in gallium



Silicon photonics integrates optical functions into compact silicon chips to achieve high-density integration.

oxide (Ga_2O_3) research. For the first time, the team successfully implemented P-type ion implantation and rapid thermal annealing on gallium oxide, followed by epitaxial growth of N-type and N^+ -type regions to form high-quality homojunction structures. This enabled the fabrication of high-performance Ga_2O_3 PN diodes, marking a significant advance in fourth-generation compound semiconductor technology. The research was published in the prestigious journal *Materials Today Advances*.

With an ultra-wide bandgap of 4.8 eV and a breakdown field strength of 8 MV/cm, gallium oxide (Ga_2O_3) outperforms silicon,

silicon carbide (SiC), and gallium nitride (GaN), making it a key material for high-voltage, high-temperature, and high-frequency applications. Japan, the U.S., and mainland China currently lead in gallium oxide research, but through the strategic collaboration with NYCU, Taiwan is rapidly closing the gap and is reinforcing its competitiveness in the global advanced semiconductor landscape.

Silicon Photonics: Breaking the Bandwidth Barrier

To address the mounting demand for high-



A breakthrough by the Semiconductor Research Center and NYCU shows strong potential for customization and integration.

speed data transfer and high bandwidth due to AI and data center expansion, HHRI has also invested in the development of silicon photonic chips.

Traditional optical systems are bulky and rely on discrete components. Silicon photonics, on the other hand, integrates the optical functions onto compact silicon chips to achieve a high degree of miniaturization. As AI has led to explosive demand for computing power and data throughput, the limitations of electrical signal transmission have become increasingly apparent, prompting a shift toward optical signaling. With chips now drastically miniaturized, there is no room for bulky optical systems alongside them, thus giving rise to the urgent need for integrated optical components.

The HHRI has designed critical components

that integrate key optical elements onto silicon photonic chips. These include high-speed modulators that enhance single-channel transmission rates, on-chip photodetectors (PDs) that eliminate the need for external conversion back to electrical signals, and metasurface interface technology that embeds beam-deflecting lenses directly into the chip.

In parallel computing, silicon photonic chips enhance single-channel transmission speeds and long-distance signaling by converting electrical signals into optical signals for low-loss transmission via fiber optics. The process addresses the longstanding problem that “electrical signals don’t travel far.” By integrating complex optical components onto a single chip and expanding the number of usable wavelengths, silicon photonic chips enable multi-channel transmission and significantly

increase the total bandwidth.

However, the pursuit of extreme miniaturization and high-speed transmission brings multiple challenges. Heterogeneous integration, which is integrating components of different materials and scales, poses a major engineering hurdle. Moreover, densely packing multiple components into a tiny space generates substantial heat, making both miniaturization and stability critical technical challenges.

In addition, the manufacturing and validation processes are both expensive and time-intensive. A single wafer run may cost millions of NT dollars, and design-to-validation cycles can span six months to a year. Furthermore, performing high-frequency measurements above 200 Gbps requires next-generation precision instruments, yet such capabilities remain limited in Taiwan. As a result, even well-designed chips might not be able to complete the full validation process.

“Our team moved swiftly. Design and tape-out were completed in just six months,” noted Dr. Hao-Chung Kuo. Despite formidable obstacles, silicon photonics research at HHRI has made significant strides, including the establishment of one of Taiwan’s few laboratories capable of conducting 200 Gbps measurements. As a result, the team’s silicon

photonics development remains globally competitive and, in certain areas, even ahead of its international counterparts.

Precision Light Control: Unlocking Miniaturization Potential

Beyond breakthroughs in Ga₂O₃ and silicon photonics, in 2024 the Semiconductor Research Center, in collaboration with NYCU, developed a novel depth-sensing and facial recognition system. This research was featured as the cover article of *Nano Letters*, a leading journal published by the American Chemical Society (ACS). It was also selected as a spotlight study in February 2024, accompanied by an exclusive interview. The work also received the Innovation Award at the 2024 I-Zone national smart display innovation showcase.

Built on depth sensing, the system determines the distance between an object and the camera lens by detecting variations in projected light points to reconstruct the object’s shape and spatial position. The most widely known application is Apple’s Face ID, which uses tens of thousands of infrared dots to generate a 3D contour of the user’s face.

The research team used metasurface engineering to design and tune nanoscale

Quick Reference

Parallel Computing

NVIDIA CEO Jensen Huang has pointed out that boosting computing power is no longer limited to chip-level miniaturization. Instead, the future lies in parallel, system-level computing, where multiple chips and boards work in concert to achieve exponential performance gains without pushing a single device to its limits.



structures on ultrathin films to precisely control the direction and focus of light. Previously requiring bulky lenses, these functions are now embedded into microchips, significantly reducing the size of optical modules while maintaining high customization and integration potential.

In addition, this technology increases the number of sensing points, widens the field of view, and significantly reduces the size of the optical module from roughly one centimeter in an iPhone to a microchip just three human hairs wide, demonstrating exceptional miniaturization potential.

Additionally, it uses photonic crystal surface-emitting lasers and monocular stereo vision architectures, which simplifies device fabrication and enables monolithic integration. Take smartphone cameras as an example. Instead of separately fabricating and assembling multiple lenses and sensors, optical elements can now be embedded directly onto the chip, boosting both efficiency and reliability.

Driving the Next Generation of Spatial Computing

The novel depth-sensing and facial

recognition system marks a major breakthrough in spatial computing. Apple's Vision Pro, for instance, relies on the real-time and accurate acquisition of depth information from the surrounding environment.

The technology developed by the HHRI-NYCU team lays the foundation for future depth-sensing applications, including AR/VR devices, drones, and smart vehicle systems. For instance, while the Apple Vision Pro contains as many as six built-in sensors, the ultracompact and lightweight nature of this technology allows AR/VR devices to become even smaller, more comfortable to wear, and far more energy-efficient.

For drone swarms of 50 to 100 units operating collaboratively, the technology facilitates efficient, precise point-to-point communication. Given drones' strict constraints on component size and battery life, this technology enables longer battery life and higher payload capacity.

By improving performance at the hardware level, this technology reduces the burden on backend software, enabling sharper recognition and more efficient optical communication. Considered a next-generation functional light source, it optimizes system performance at the lowest level.

Quick Reference

Monolithic Integration

Traditionally, nanoscale optical sensors were fabricated separately, lasers on one wafer, nanostructures on another, and then assembled later. Monolithic integration, by contrast, embeds nanoscale structures directly onto the laser chip, enabling the laser to emit a beam with specific properties and spatial profile at the point of light emission.



Next-generation Communications Research Center

PEARL Enters In-Orbit Verification: Ushering in the 6G Era

As 5G becomes increasingly widespread, the blueprint for next-generation 6G communications is coming into focus. The most critical shift is the full integration of Non-Terrestrial Networks (NTN), which overcomes the geographic limits of terrestrial base stations. NTN will enable uninterrupted connectivity in the air, at sea, and in remote regions. The core technology enabling this vision is low-Earth orbit (LEO) satellite communications.

Integrating AI, Sensing Technologies, and Satellite Communications

With the 6G era approaching, the Next-generation Communications Research Center (NCRC) has launched the PEARL Satellite Program. The initiative is designed to conduct proof of concept for LEO communications and lay the groundwork for future development. In addition to collecting space environment data, the program will establish a comprehensive workflow for satellite development and

systems engineering.

The PEARL program was initiated in 2021, and after nearly two years of research, development, integration, and testing, it achieved a major milestone with its successful launch in late 2023. While 2023 focused on pre-launch tasks, including system assembly and integration, space environment testing, functional verification, and pre-launch preparations, 2024 shifted toward in-orbit operations, including early orbit control, post-stabilization procedures, and data collection and analysis.

The PEARL program includes two satellites: PEARL-1H and PEARL-1C. The names represent Hon Hai (H) and National Central University (C), respectively. PEARL-1H is equipped with an optical lens developed by Rayprus Technologies Ltd., a Hon Hai subsidiary, and a phased-array antenna from Tron Future Tech. PEARL-1C is equipped with a space environment probe developed by National Central University (NCU).

In 2024, the NCRC team completed the construction of a ground station atop Hon

Hai's Neihu building. Equipped with three different types of antennas and connected to indoor servers, the station enables satellite communication, data transmission, and control. It tracks satellite orbits in real time, displays their positions, and schedules communication windows.

Beyond building its own ground station, the team also collaborated with NCU to access additional ground stations. It also leased high-latitude stations in Norway to extend satellite contact time and improve data reception. Apart from receiving beacon signals and monitoring satellite health status, the ground stations also transmit commands to the satellite to retrieve data and images. To date, the satellites have successfully downlinked multiple space images, providing valuable support for ongoing research.

As Taiwan's first broadband communications satellite and the industry's first satellite designed specifically for 6G non-terrestrial network (NTN) experiments, PEARL aims to validate key technologies for the upcoming 6G era, while also investigating how the space environment affects satellite performance and communication quality.

LEO satellites, however, are not meant to replace terrestrial base stations but to serve

as a complementary and backup system. In remote mountains, at sea, or in uninhabited regions beyond the reach of ground infrastructure, LEO satellites make seamless connectivity possible.

Tracking Solar Activity to Improve Satellite Performance

In addition to its communications payload, PEARL is equipped with a Compact Ionospheric Probe (CIP) to measure electron density in the ionosphere along the satellite's flight path.

Solar storms can trigger significant fluctuations in ionospheric density, degrading communication quality. They also produce large amounts of ions that heat and expand the atmosphere, increasing air density and atmospheric drag at orbital altitudes, which can cause gradual orbital decay.

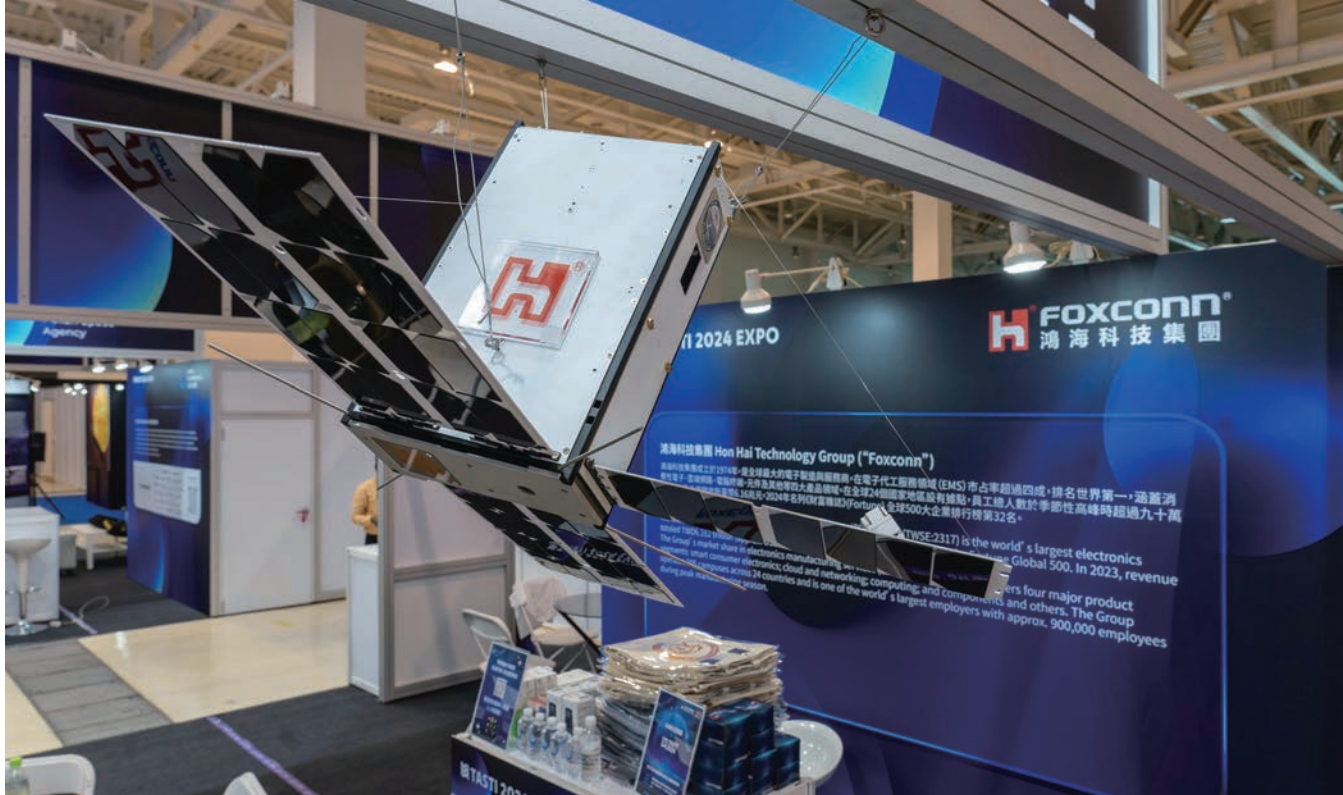
In 2024, during peak solar activity, the NCRC team used PEARL's onboard CIP to observe ionospheric changes and cross-check the data against satellite altitude. The team thus gained a deeper insight into how solar activity affects satellite operations and communications.

Quick Reference

6G

The sixth generation of mobile communications is expected to emerge around 2030. Compared with 5G, 6G will deliver higher bandwidth, ultra-low latency (<1 ms), and faster data rates of up to 1 Tbps. It will integrate AI, sensing, terrestrial, and communications, enabling immersive applications such as holographic video calls, mixed reality, and smart cities.





The PEARL satellite project validates the concept of low Earth orbit communications, testing technical feasibility while collecting space environment data to support end-to-end system development.

Key Technologies for Ushering in the 6G Era

Following its launch in 2023, PEARL faced several challenges in its early orbit operations.

First is attitude instability. Immediately after separation from the rocket, the satellite tumbled rapidly. Engineers used attitude sensors, magnetorquers, and reaction wheels to gradually stabilize its orientation.

Second are the extreme temperature swings. PEARL completes one orbit around Earth every 90 minutes, during which it experiences dramatic temperature shifts of up to 130°C in 45 minutes. These swings tested the resilience of the satellite's structure and components.

Third, imaging calibration. Initial images returned from the satellite were completely black. The team had to send commands from the ground to adjust camera exposure settings until clear images were obtained. In addition, the satellite's attitude sensing and control systems also required calibration via ground

commands to ensure proper operation.

Lastly, satellite communications is difficult. Functioning like a mobile base station, PEARL orbits Earth every 90 minutes, with only brief contact windows over Taiwan. Its high velocity causes frequency shifts, a phenomenon known as the Doppler Effect. This is comparable to a radio conversation where one side constantly adjusts channels, making it difficult for the other to maintain clear reception. Engineers overcame this challenge by using predictive models to adjust uplink and downlink frequencies in real time.

After months of effort, these challenges were gradually resolved. Today, PEARL can switch between multiple modes depending on mission requirements: three-axis stabilization mode to maintain a steady attitude, target tracking mode to lock onto communication targets, and sun-tracking mode to adjust its orientation so that sunlight strikes the solar panels perpendicularly to optimize power generation and maximize charging efficiency.

As of May 2024, PEARL has completed its

early orbit operations and entered a stable operating phase. Real-time monitoring from the ground station indicates that the satellite's charge-discharge cycles, voltage levels, and power curves are stable and functioning normally.

Satellites Driving the 6G Connectivity Revolution

As we enter the 6G era, NCRC Director Jen-Ming Wu highlights two transformative trends:

First, multi-layered 3D networking. Future 6G infrastructure will no longer be confined to terrestrial base stations; it will incorporate low-Earth-orbit satellites to form a three-dimensional, multi-layered architecture.

Second, the 6G era will offer ubiquitous connectivity. This will address current blind spots in mountainous regions, remote areas, and oceans, enabling seamless connectivity across open spaces and making network access genuinely ubiquitous.

The successful launch and in-orbit validation of PEARL hold strategic importance for Hon Hai's "3+3" transformation strategy. As a core enabling technology, satellite communications will tightly integrate with AI, semiconductors, and other advanced domains to serve as a vital link across platforms.

Looking ahead, the NCRC will continue to use valuable data and operational insights from PEARL's time in orbit as groundwork for the design and planning of next-generation satellites with enhanced functionality and greater system stability. In parallel, the team is pursuing foundational research and software platform development, aiming to establish a complete ecosystem for satellite communications research and validation.

Director Wu emphasized that the goal is to expand satellite capabilities beyond simple point-to-point links into comprehensive service platforms so as to secure a key role for Taiwan in the global LEO satellite supply chain.

As the world moves toward 6G, the PEARL Satellite Program is not only a milestone in Taiwan's LEO satellite journey but also a testament to its innovation, linking academia and industry. From orbital control to signal compensation, space environment sensing to communications validation, PEARL demonstrates the potential of cross-disciplinary collaboration. These accumulated achievements will accelerate the real-world deployment of satellite technologies, paving the way for a ubiquitous, integrated space-terrestrial smart network and positioning Taiwan for leadership in the global 6G landscape.

Quick Reference

Solar Storms

Solar storms are geomagnetic disturbances caused by high-energy charged particles released by the Sun, such as solar flares and coronal mass ejections. When these particles reach Earth, they interfere with the earth's magnetic fields and affect satellites, navigation systems, and radio communications. They can even cause auroras or disrupt power systems.



Table 1. Milestones of the PEARL Satellite Program

Date	Milestone
2023/11/12	Satellite launched aboard SpaceX rocket; UHF antenna deployed; first two-way communication established.
2023/11/28	NORAD tracked its orbital path; PEARL-1H was assigned catalog number 58265.
2023/12/12	First telemetry data downlinked; system stability and health monitoring initiated.
2023/12/25	Subsystems calibrated, including UHF, On-Board Computer (OBC), batteries, and solar panels.
2023/12/31	Tumbling angular velocity measured; attitude sensors and actuators calibrated.
2024/01/11	Intermittent rapid detumbling maneuvers were executed and validated.
2024/01/25	Magnetometer deployed; Y-Thomson de-tumbling procedure performed.
2024/02/02	Magnetometer calibration was conducted; in-orbit performance was verified against models.
2024/03/02	Reaction wheel testing initiated; three-axis stabilized flight mode confirmed.
2024/03/13	Solar panels deployed; camera payload uncovered; test imaging conducted.
2024/03/18	Solar-tracking mode was verified by comparing solar sensor vectors, geomagnetic vectors, and three-axis attitude angles.
2024/04/02	First six images were downlinked; underexposure and overexposure issues were observed.
2024/04/09	OBC scheduling functions tested.
2024/04/20	Ground-target tracking mode validated.
2024/05/15	Camera exposure parameters adjusted for day/night sides; clearer space images obtained.
2024/06/07	Cyclical variations in battery temperature, voltage, and current were confirmed across day/night transitions.
2024/07/30	Battery management reconfigured: aggressive charging in low temperatures; conservative discharging at low voltage.
2024/08/15	Rooftop dish antenna installation completed at Neihu ground station.
2024/10/22	NCC experimental R&D telecom license obtained.
2024/11/20	Antenna pointing and Doppler compensation errors measured; impact on packet transmission in time-varying channels analyzed.
2024/12/25	GNSS data was cross-checked with orbital propagation; RTC clock drift was confirmed.

Source: Next-generation Communications Research Center, Hon Hai Research Institute

Trapped-Ion Quantum Computing Laboratory

Precision Ion Trapping and Control: Paving the Way for the Future of Quantum Computing

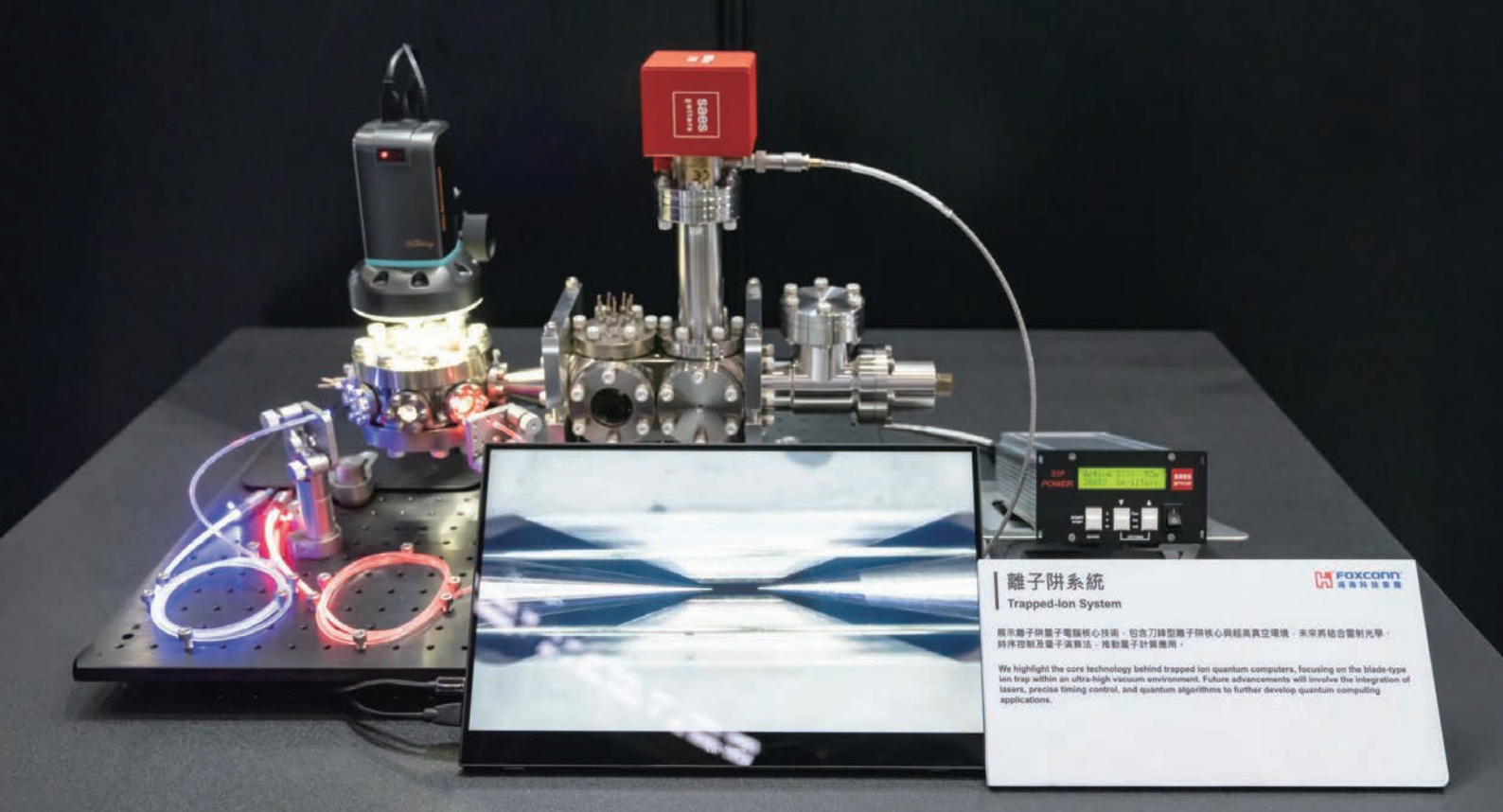
An ion trap is a device that uses oscillating electric fields to confine charged particles. At the Trapped-Ion Quantum Computing Laboratory, the research team works with naturally occurring ytterbium-171 atoms. By ionizing one of the atom's outermost electrons, the atom becomes electrically charged. The ion is then precisely trapped in a vacuum using radio-frequency (RF) fields generated by three pairs of electrodes, with laser cooling applied to stabilize and localize the ion. As more ions are trapped, adjusting the electric potential distribution allows them to naturally align into a linear ion array.

Trapped ions of the same isotope are physically identical, which is a gift from nature. This eliminates the fabrication variability that affects many artificial qubit platforms, making trapped ions ideal qubit candidates. Because quantum states are extremely delicate, experiments must be performed under ultra-high vacuum conditions, which are comparable to outer space, in order to minimize interference caused by environmental noise and stray particles.

High particle temperatures lead to increasingly random and vigorous motion, which undermines the precision of quantum state storage and control. However, in a vacuum, the absence of friction means that ions cannot lose energy naturally. Their motion cannot be reduced passively to levels near absolute zero.

To address this challenge, the research team employs laser cooling. While illuminated by red-detuned laser beams, fast-moving ions absorb photons traveling against their motion. Momentum transfer reduces their motion, cooling them to near absolute zero within milliseconds. Meanwhile, the surrounding components, including the vacuum chamber walls, remain at room temperature. This greatly alleviates the otherwise stringent cryogenic requirements of quantum computing hardware.

Another advantage of ion qubits is their exceptional connectivity. Within the same array, ions interact via shared vibrational modes, enabling logic operations between any pair of qubits. With precise electrode control, ions can even be shuttled between arrays, supporting scalable and modular quantum architectures.



Future ion-trap systems will integrate lasers, timing control, and quantum algorithms to advance quantum computing applications.

By contrast, artificial qubit platforms are constrained by physical wiring layouts, and thus the interactions are limited to adjacent qubits, resulting in significantly lower connectivity.

From Individual Ions to Ion Arrays

The Trapped-Ion Quantum Computing Laboratory was inaugurated on October 15,

2023. As equipment was gradually installed, the research team began assembling the ion trap experimental system. After a year of dedicated work, lab researchers successfully trapped clusters of ytterbium ions in October 2024 and, by year's end, obtained the first image of a single ion. Within weeks, they achieved a breakthrough and created a stable ion array. By mid-2025, the team was able to produce stable arrays containing more than fifty ions.

Quick Reference Quantum Bit

A quantum bit, or qubit, is the basic unit of quantum information. Unlike a classical bit, which can only be 0 or 1, a qubit can exist in a superposition of both states simultaneously. When multiple qubits become entangled, they exhibit quantum parallelism, enabling quantum computers to solve certain problems far more efficiently than their classical counterparts.

The process appeared straightforward, but it was full of challenges.

For instance, environmental fluctuations can cause laser frequency drift, requiring active frequency stabilization to lock the laser to a precise reference. The laser's linewidth must also be tightly controlled to prevent unintended state transitions in the ions.

In addition, quantum state readout requires efficient collection of the faint ion fluorescence emitted by ions after excitation. By tuning the laser to a specific frequency, only ions in the "1" state are excited, while those in the "0" state remain unaffected. The process requires carefully designed optical paths, lens arrangements, spatial resolution tuning, low-light amplification, and signal processing techniques. These elements work together to extract the fluorescence profile of each ion, allowing accurate determination of its quantum superposition between 0 and 1.

Control Precision and Connectivity

Beyond qubit count, the team places particular emphasis on the precision of ion control and the connectivity between qubits,

both considered core performance metrics. Although the team has successfully trapped more than fifty ions to date, only those whose quantum states can be controlled with high precision qualify as true qubits. Consequently, the team's short-term goal remains focused on achieving high-fidelity control over 5 to 10 qubits.

The ion trap core has also continued to evolve. In 2022, the team introduced a first-generation single-zone blade-type design, followed by a second-generation multi-zone layered architecture in 2023. The first-generation core has already been installed in experiments, successfully capturing and manipulating ion arrays to demonstrate its effectiveness.

Meanwhile, the multi-zone trap design is still under optimization. According to Dr. Guindar Lin, Director of the Trapped-Ion Quantum Computing Laboratory, experiments involving both the first- and second-generation cores are expected to run in parallel between 2025 and 2026, each tasked with different roles such as ion control and system validation.

The evolution from the first- to the second-generation ion trap marks a shift from the simple to the complex. The first-generation

Quick Reference

Superconducting qubits

A qubit implemented with superconducting materials and Josephson junctions. At cryogenic temperatures, superconductors exhibit zero electrical resistance, enabling stable quantum current oscillations. Microwave control enables transitions and superpositions between quantum states, thereby supporting the storage and processing of quantum information. Although superconducting qubits require strong cooling systems to maintain superconductivity, they are compatible with semiconductor fabrication processes and benefit from a mature technological ecosystem.



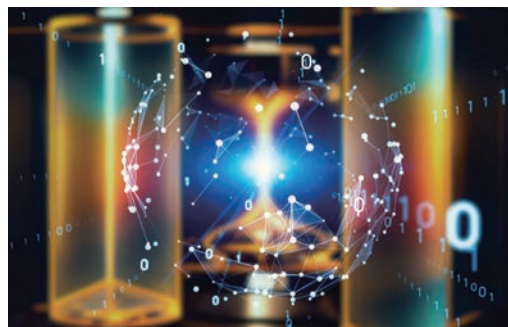
core features a relatively simple and stable design, suitable for testing, training, and providing calibration data and physical parameters. The second-generation trap adopts a multi-zone architecture, in which the trap is segmented into multiple regions with independently applied voltages. This allows researchers to dynamically reshape the potential landscape to precisely control ion movement for different tasks, such as bringing specific ions together to perform logic operations or separating them for storage when interaction is not required.

Current first- and second-generation prototypes rely on precision machining, which makes the system difficult to scale. To expand from tens of qubits to hundreds of thousands or even millions, more stable semiconductor processes will be required so as to achieve system miniaturization and optical integration.

From Ion Trap Experiments to Universal Quantum Computers

Quantum computer performance is evaluated through multiple metrics that factor in qubit count, connectivity, and coherence time. Among competing platforms, trapped-ion systems stand out in the current “noisy intermediate-scale quantum” (NISQ) era for their superior connectivity and coherence. Looking ahead to scalable quantum computing architectures, silicon photonics presents a technically demanding but promising pathway.

To explore how future semiconductor processes might be applied to ion-trap systems, the Trapped-Ion Laboratory has collaborated with the Semiconductor Research Center, Academia Sinica, and National Yang Ming Chiao Tung University.



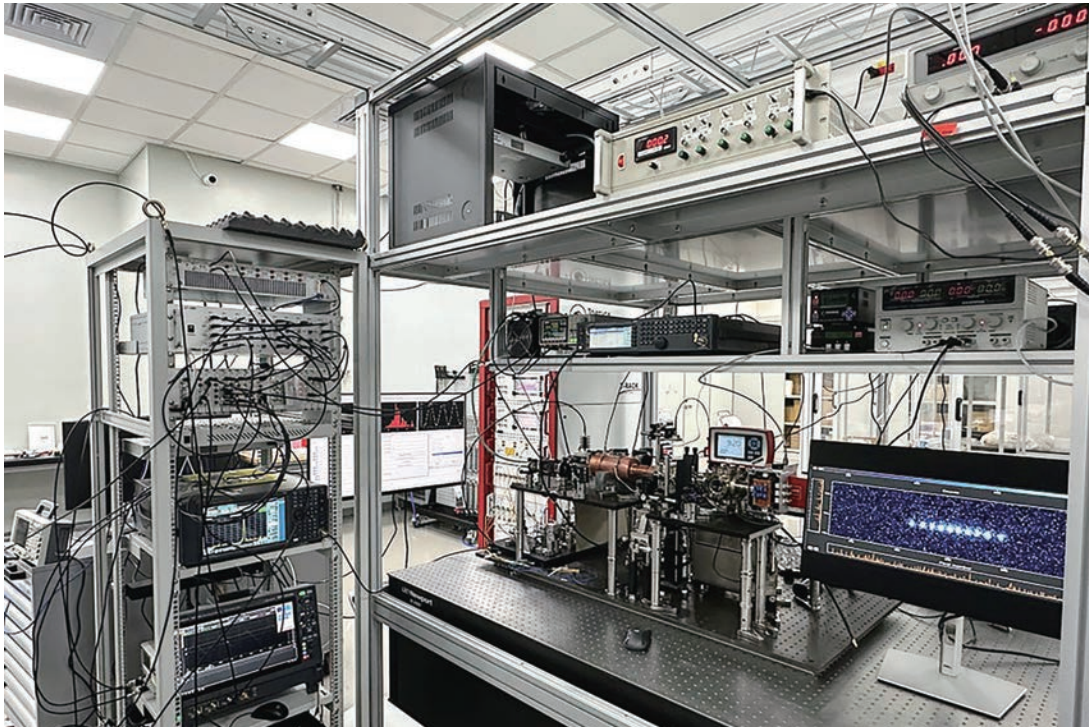
Qubits in superposition enable quantum computing to exceed current computing limits with greater efficiency.

The partnership focuses on forward-looking development, with silicon photonics as a key enabling technology.

At the million-qubit scale, assigning a dedicated laser source to each ion is not only impractical but also prohibitively expensive. Silicon photonics offers a scalable solution by leveraging semiconductor processes to produce integrated waveguides on the substrate. These waveguides route light beneath target ions, couple it into free space, and focus it precisely onto individual ions.

However, the light required to control specific ions often falls within frequency ranges that are strongly absorbed by common silicon photonic materials, leading to low efficiency and thermal management issues. Globally, the use of silicon photonics is still at its early stages of development. Thus, integrating silicon photonics into ion-trap systems continues to pose significant challenges. These include identifying new materials with mature processes and specific wavelengths to designing components that meet system requirements.

Looking ahead, Dr. Guin-Dar Lin outlines a staged roadmap for the Trapped-Ion



The Trapped-Ion Quantum Computing Laboratory focuses on forward-looking research, exploring how future semiconductor processes can be applied to ion trap systems. Pictured here is the laboratory at the Baogao Smart and Industrial Park in Xindian, New Taipei City.

Laboratory.

Short-term goal (by 2027): Building a universal ion-trap quantum computer prototype with 5 to 10 qubits. “Universal” refers to general-purpose hardware, such as a classical computer, that can execute diverse tasks through programmable code rather than being limited to a single function. However, given the limited qubit count, such a prototype will not yet be able to solve practical problems.

Medium-term goal: Developing the key technologies required for scalable quantum computing architectures. This includes transitioning from current 3D ion-trap structures to 2D designs, namely, ion-trap chips fabricated using semiconductor

processes, ion-shuttling techniques, and the integrated optical and electronic components for qubit control. Ultimately, the ion-trap system will be further miniaturized and modularized, with enhanced stability and connectivity.

Long-term goals: Establishing scalable architectures through stable, modular interconnections to support hundreds, thousands, or even tens of thousands of effective qubits. As hardware technologies mature, the laboratory will collaborate with the Quantum Computing Research Center to implement fault-tolerant, error-corrected algorithms, delivering the computational power needed for advances in AI, intelligent platforms, energy storage, and pharmaceutical

development.

Cultivating Expertise and Building Ecosystems

Taiwan has long prioritized research areas closely tied to existing industrial sectors. However, emerging sciences such as quantum technologies, optics, atomic and molecular physics remain comparatively underdeveloped. With the quantum industry chain still in its formative stages and the pull of established overseas quantum research hubs and semiconductor sectors, cultivating and retaining domestic quantum talent remains a significant challenge.

According to Dr. Guin-Dar Lin, the current team at the Trapped-Ion Laboratory is composed primarily of physicists with expertise in theoretical and experimental quantum optics and atomic physics. However, quantum computing development is inherently interdisciplinary, and the lab has consistently welcomed talent from electrical engineering, electronics, materials science, and computer science. By generating increasingly mature research outcomes, the

lab hopes to build momentum and attract more aspiring researchers to the quantum technology field.

“Quantum computing is undoubtedly the ‘holy grail’ of the next generation,” Dr. Lin emphasized. “Its advancement hinges on repeated trial and error, accumulated experience, and the high-level integration of talent, resources, and technologies. The Trapped-Ion Laboratory serves as a crucial experimental platform for Taiwan’s industry. Moving forward, the laboratory will continue to invest resources and connect domestic and international academic, governmental, and industrial expertise to achieve results recognized by the global industry.”

Quantum computing is widely regarded as a key technology for surpassing the current computational limits, with ion trapping emerging as one of the most promising hardware platforms.

The establishment of the Trapped-Ion Laboratory not only demonstrates the industry’s commitment to advancing quantum technology but also establishes a critical foundation for Taiwan’s quantum ecosystem.

Quick Reference

Quantum Error Correction



Qubits, the building blocks of quantum computation, are highly susceptible to environmental disturbances, a phenomenon known as decoherence. Without correction, errors can accumulate rapidly during computation, producing incorrect results. Quantum error correction encodes a single logical qubit across multiple physical qubits, allowing errors to be detected and corrected even if some qubits fail. Therefore, quantum error correction is essential for the reliable execution of quantum algorithms.

Quantum Computing Research Center

Building Efficient Algorithms with Error Correction, Clustering, and Noise Mitigation

The concept of quantum computing began to take shape in the 1980s, and a major breakthrough came in 1994 with the introduction of Shor's algorithm, which drew worldwide attention from the scientific community. Today, quantum computers with hundreds of qubits have already been built.

However, qubits are extremely susceptible to environmental noise. As their number increases, error rates grow exponentially. To ensure computational accuracy, quantum error correction (QEC) is essential for detecting and correcting these errors.

The Golden Triangle of Quantum Error Correction

Error rates in today's quantum computers remain high. Even with a fidelity of 99.9999%, about one error per million operations, a practical quantum algorithm may require up to 10^9 computations. Without error correction, a single error could invalidate the entire computation.

For this reason, quantum error correction

(QEC) has been a central focus of the Quantum Computing Research Center (QCRC) since its founding. At its core, QEC relies on redundancy.

For example, in classical systems, a bit "1" can be transmitted three times as "111." Even if one bit flips to "101" in error, the receiver can still correctly identify the original bit as "1" by majority voting.

In quantum systems, however, error correction is far more complex. It involves balancing three critical parameters: N , the number of encoded qubits; K , the number of logical (original) qubits; and D , the number of correctable errors. As the number of correctable errors increases (i.e., a larger D), the required redundancy ($N-K$) also grows, which in turn reduces the amount of usable data (K) that can be transmitted. The QCRC is dedicated to finding optimal trade-offs among these three parameters.

International Collaboration for Optimal Parameters

In addition to minimizing errors,

measurement efficiency is also critical. Ideally, error-correcting codes should be low-density, meaning that only a small subset of qubits needs to be measured to identify and fix errors, rather than examining all qubits. This ensures both efficiency and precision.

Another key design consideration is geometric locality; the qubits to be measured should be physically close to each other rather than widely dispersed. This helps shorten the actual distance between qubits, minimizing latency and reducing the complexity of quantum hardware design.

In other words, the challenge of QEC lies in encoding and decoding: how to detect and correct errors rapidly and accurately while using as few qubits as possible. This problem has remained unresolved for decades.

In 2023, QCRC collaborated with Caltech (USA) and the Weizmann Institute of Science (Israel) to propose an optimal construction method for quantum low-density parity-check (qLDPC) codes and develop a high-efficiency linear-time decoder whose runtime scales with qubit count. This breakthrough enables data protection with minimal redundancy while achieving optimal error-correction performance, resolving a challenge that had persisted for over two decades.

Building on this, in 2024 the team further

integrated geometric locality into their error-correcting codes. These new designs not only minimize the number of measurement points needed to identify errors but also physically cluster those points, significantly reducing the complexity of quantum hardware design.

The results, which combine optimal parameters with geometric locality, were presented at QIP 2024, one of the world's leading quantum computing conferences. "This is not only a technical breakthrough," noted QCRC Director Min-Hsiu Hsieh, "it also demonstrates that our team is now among the global leaders in quantum error correction."

From Social Networks to Logistics: Delivering Quantum Solutions

In addition to breakthroughs in QEC, QCRC also collaborated with Université Paris to develop a quantum graph clustering algorithm. This approach offers more efficient solutions to problems that can be abstracted into graph structures, as well as clustering and classification tasks.

For instance, quantum graph clustering can analyze nodes within a network to map complex social connections, such as distinguishing individuals with the same name

Quick Reference

Shor's Algorithm

Shor's algorithm is a quantum algorithm for finding the prime factors of an integer in polynomial time, thereby breaking RSA encryption. It remains one of the most iconic demonstrations of quantum computing's ability to surpass classical computing.



across different communities and analyzing complex interpersonal relationships. The team demonstrated a clear quantum advantage. Compared to the classical algorithm's computational complexity of $O(\sqrt{N})$, the graph clustering algorithm developed by QCRC achieves a complexity of $O(\sqrt[3]{N})$.

This means that as problem sizes increase, the graph clustering algorithm developed by QCRC requires computational resources that increase more slowly, allowing quantum computers to tackle larger problem sizes than classical systems under the same resource constraints.

In addition, the study was the first to establish a theoretical lower bound for such problems, precisely defining the performance limits of classical algorithms. This is a critical milestone in computer science, as it enables researchers to assess the efficiency of corresponding quantum algorithms with theoretical certainty. With this, the team can confidently apply high-efficiency quantum algorithms to real-world problems without wasting resources on inefficient methods.

More importantly, applications of quantum graph clustering algorithms are not limited to social media. Its true potential lies in recasting complex real-world problems into graph clustering problems that can be solved more efficiently with quantum algorithms. Examples include matching drivers and passengers in ride-sharing services, optimizing logistics, streamlining production line workflows, and improving industrial manufacturing efficiency.

Noise Mitigation to Enhance Computational Accuracy

Another major 2024 achievement from QCRC is the breakthrough in quantum state

tomography.

While quantum computers are powerful, they are also highly susceptible to noise. To realize their computational advantage, noise must be reduced below a certain threshold, making signal denoising in quantum states particularly important. A quantum state refers to the configuration of a quantum system. Its preparation is complex and requires computation to verify correctness. However, quantum states cannot be directly observed; only partial measurement results can be obtained under specific conditions.

Certain quantum states are essential for realizing quantum advantage. Without them, some quantum operations are no better than classical computation. Efficiently generating and accurately verifying these quantum states is therefore a central challenge.

Quantum state tomography addresses this issue by reconstructing qubit states through a series of precise measurements, ensuring the accuracy of hardware operations. A key technique is the Riemannian gradient descent, which significantly reduces the time required for quantum state reconstruction.

Breaking the Bottleneck in Quantum State Reconstruction

Quantum state is typically represented by matrices, whose size grows exponentially with the number of qubits. As a result, the amount of data required for quantum state tomography increases drastically. This makes data collection and full state reconstruction prohibitively demanding and time-consuming.

Fortunately, quantum states are not entirely random; they follow intrinsic structures. By exploiting these patterns with the Riemannian gradient descent, the



Quantum state tomography marked a major milestone for the Quantum Computing Research Center in 2024.

QCRC team greatly improved quantum state reconstruction efficiency. Their results were published in *Physical Review Letters*, highlighting the international significance and academic rigor of their work.

Looking ahead, Director Hsieh envisions QCRC continuing to advance along three key areas: hardware enablement, software algorithms, and real-world applications. Together, these efforts aim to accelerate the commercialization of quantum computing.

Information Security Research Center

Building a Comprehensive and Forward-Looking Cybersecurity System for the Quantum and AI Era

In 1994, the advent of Shor's algorithm theoretically demonstrated that once large-scale quantum computers become available, existing public-key cryptosystems will face severe risks. The danger lies not in human error but in the fact that the fundamental mathematical problems underpinning public-key cryptography could be completely cracked.

More importantly, migrating the current public-key systems to post-quantum cryptography will inevitably require substantial time and resources, including the selection of post-quantum standards, system upgrades, and software/hardware deployment. This represents a costly and time-intensive transformation.

Therefore, even as quantum computer hardware and algorithms continue to evolve, research in post-quantum cryptography has already become a global priority to prepare for future cybersecurity threats and migration costs.

Cybersecurity Defense in the Quantum Era

To counter cybersecurity threats posed by

quantum computers, the industry is pursuing two main defense strategies.

First, quantum cryptography.

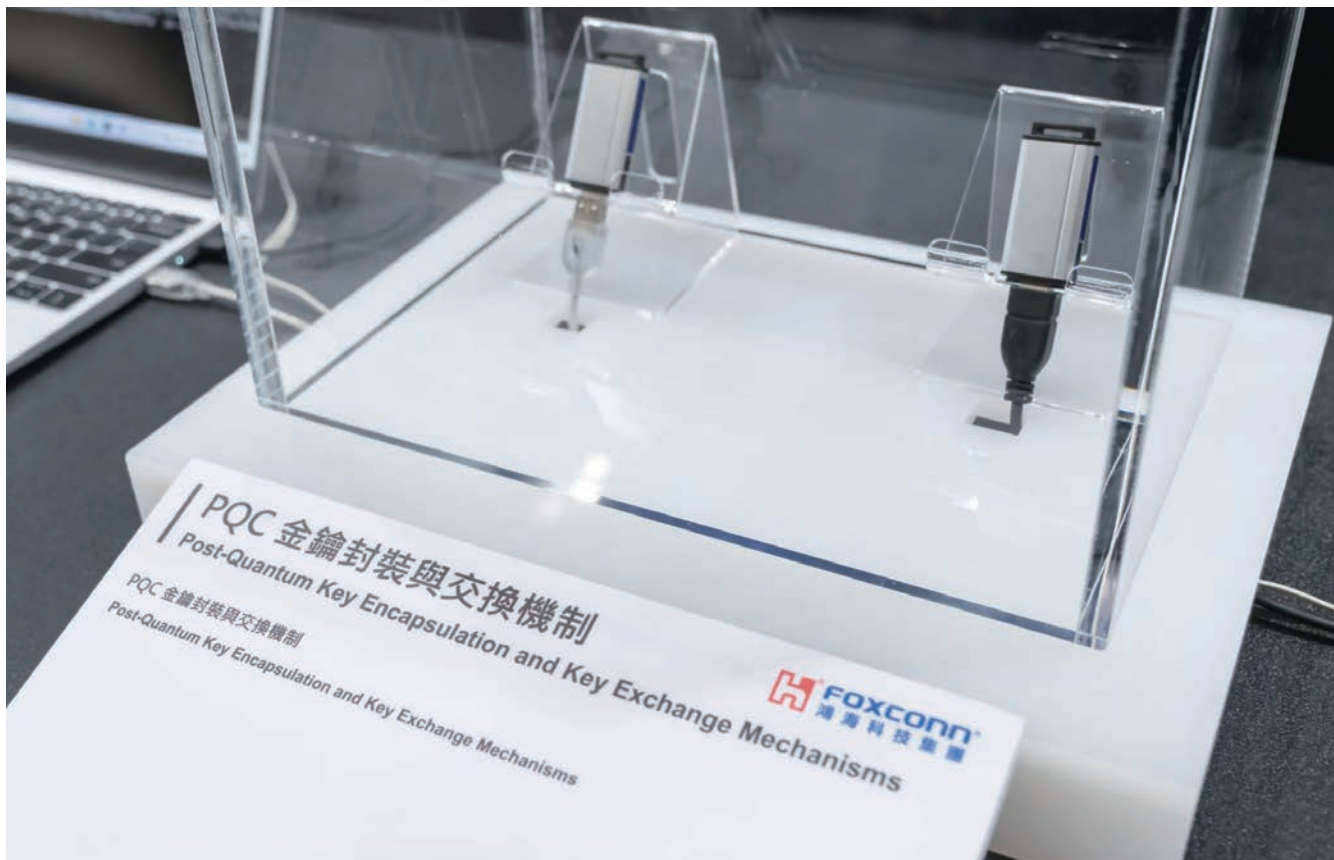
Based on the unique properties of quantum mechanics, the most well-known example is Quantum Key Distribution (QKD). Quantum cryptography offers extremely high security but remains difficult to implement primarily due to cost, technology, and equipment constraints.

Second, post-quantum cryptography (PQC).

Building on traditional cryptographic approaches, PQC targets mathematical problems that are difficult for quantum computers to solve, using them as the foundation for new cryptosystems. While quantum computers are powerful, they are not omnipotent; they excel only at certain problems, and PQC leverages this limitation to establish robust defenses.

Post-Quantum Cryptography as a Critical Discipline

The timeline for the emergence of large-scale quantum computers remains uncertain,



Post-quantum cryptography (PQC) is a key defense strategy against cybersecurity risks posed by quantum computers.

but the cybersecurity threats they pose are already foreseeable. The global cybersecurity community has therefore turned to developing quantum-resistant cryptography, giving rise to PQC.

Faced with emerging threats, the U.S. federal government has stated that existing public-key cryptosystems, such as RSA and ECC, should begin to be deprecated by 2030 and disallowed after 2035, making PQC research and deployment an urgent priority.

To address the quantum threat, the National Institute of Standards and Technology (NIST) has launched a standardization process

for PQC and has already selected multiple algorithms for inclusion in the Federal Information Processing Standards (FIPS).

The Information Security Research Center (ISRC) has actively participated in the Post-Quantum Cryptography competition organized by NIST. Its research was officially published by NIST in July 2023, signaling NIST's recognition of ISRI's contributions. In 2024, the ISRC achieved a key milestone by implementing FIPS 203 (ML-KEM) on microcontrollers (MCUs) and validating the correctness of key exchange operations, demonstrating its mastery of PQC.



The Information Security Research Center advances PQC research in preparation for the post-public-key era.

However, while PQC algorithms are resistant to quantum attacks, they often lag behind current RSA and ECC standards in computational efficiency, public key size, and signature specifications. As a result, the ISRC has prioritized efforts to optimize PQC implementation for integration into existing hardware, ensuring smooth enterprise migration to quantum-resistant systems.

Cybersecurity Challenges and Strategies in the AI Era

As AI technology matures, enterprise operations are becoming smarter and more efficient. However, AI is also reshaping the

cybersecurity landscape in three critical ways:

First, hackers are using AI to accelerate, refine, and customize attacks against specific targets. Second, cybersecurity defenses must adapt AI to enable dynamic learning and real-time adaptation, overcoming the limits of static, rule-based detection. Lastly, AI itself carries inherent risks. If training data is maliciously corrupted, models may be implanted with backdoors, introducing new security threats. Clearly, AI is not only a driver of industrial innovation but also a decisive factor in cybersecurity.

To counter these risks, ISRC is developing AI-powered dynamic defense systems. These technologies strengthen static detection while

enabling continuous learning and adaptation to new attack methods. In addition, the technology also integrates ISRC's AI threat detection model with the global Cyber Threat Intelligence (CTI) database, drawing on worldwide data to convert threat intelligence into actionable model insights.

The results show a substantial improvement in detecting previously unknown attacks, with related findings published in leading international journals. This means that enterprise networks and connected production-line devices will be fortified with more resilient, proactive defenses, capable of responding to threats before they materialize and mitigating the risk of major financial and operational losses.

Yet the challenges do not end there. Another hidden risk lies in the training of AI large language models.

During large-scale training, models may inadvertently absorb unsafe or harmful behavioral patterns that can be triggered under specific conditions, resulting in latent security risks. To address this issue, ISRC has developed an algorithm to precisely pinpoint parameters associated with "toxic speech" and apply weight subtraction techniques to significantly suppress unsafe behaviors while

retaining the model's full functionality and performance.

This research has been accepted by top-tier international conferences and recognized by peer reviewers. Looking ahead, the technique can be applied in customer service, education, and healthcare, and it can suppress model parameters linked to toxic behavior to help AI "forget" unsafe patterns. This approach reduces risks of malicious manipulation, ensures more stable and trustworthy outputs, and promotes public trust in AI applications across industries such as customer service, education, and healthcare.

The breakthroughs in real-time defense and risk removal have established a new foundation for AI cybersecurity. Moving forward, ISRC will continue to advance model safety, explainability, and output verification, collaborating with industry and academia to accelerate deployment. Industry provides real-world validation, while academia contributes frontier theory and techniques. Together, they accelerate the evolution of AI-powered cybersecurity. The ultimate goal is an adaptive cybersecurity network capable of real-time learning and response to safeguard enterprises and users across the digital battlefield.

Quick Reference

Public-Key Cryptosystem



A cryptographic system that uses a pair of keys: a public key, which can be freely shared, and a private key, which is held exclusively by the owner. Even if the public key is known, the private key cannot be deduced, effectively ensuring secure communication.

Building a Resilient Cybersecurity Defense

Hon Hai Technology Group’s cybersecurity governance aims to establish a comprehensive and robust cybersecurity system that extends from top-level commitment to daily operations. This top-down approach fosters a strong cybersecurity culture, supported by planning and investments consistent with the Group’s specific needs. In addition, collaboration across workgroups ensures policies are effectively implemented.

At the heart of these efforts is the Cybersecurity Governance Committee, chaired by Hon Hai Chairman Young Liu. Committee members include top executives from key subsidiaries, chief information and network officers, and the ISRC director, with senior leaders from finance, HR, legal, and audit departments participating on a project basis as needed.

A Secretariat supports strategy planning and convenes regular committee meetings to report progress and strategic direction to senior leadership, reinforcing organizational resilience and protecting customer privacy and assets.

The Committee also oversees two working groups. The Cybersecurity Governance Working Group develops cybersecurity strategies, policies, and standards to ensure regulatory compliance. The Cybersecurity Operations Working Group implements and maintains security architecture, devices, and risk management mechanisms to ensure operational effectiveness.

According to Wei-Bin Lee, ISRC Chief Executive Officer and Director, the Committee’s work is defined by two key features.

First, establishing common standards and language. Hon Hai Technology Group spans a wide array of business units, each of which defined, assessed, and reported cybersecurity incidents differently. The Committee has therefore unified incident classification principles and reporting levels across the Group, enabling consistent communication and resilience across business units.

Second, the committee has built a comprehensive defense framework centered on ransomware that spans prevention, detection, and recovery. The initiative begins with the establishment of Emergency Response Centers at both the central and

Quick Reference

FIPS 203

ML-KEM (Kyber) is among the first PQC standards selected by NIST. FIPS 203, issued by NIST in 2024, is the official key establishment standard that incorporates Kyber into the federal cryptographic framework. It specifies Kyber’s implementation methods and parameters to support secure deployment in government and industry.



As cyber threats become more complex and diverse, security monitoring remains a critical line of defense for enterprises.

subsidiary levels, which coordinate group-wide response teams to enhance resilience.

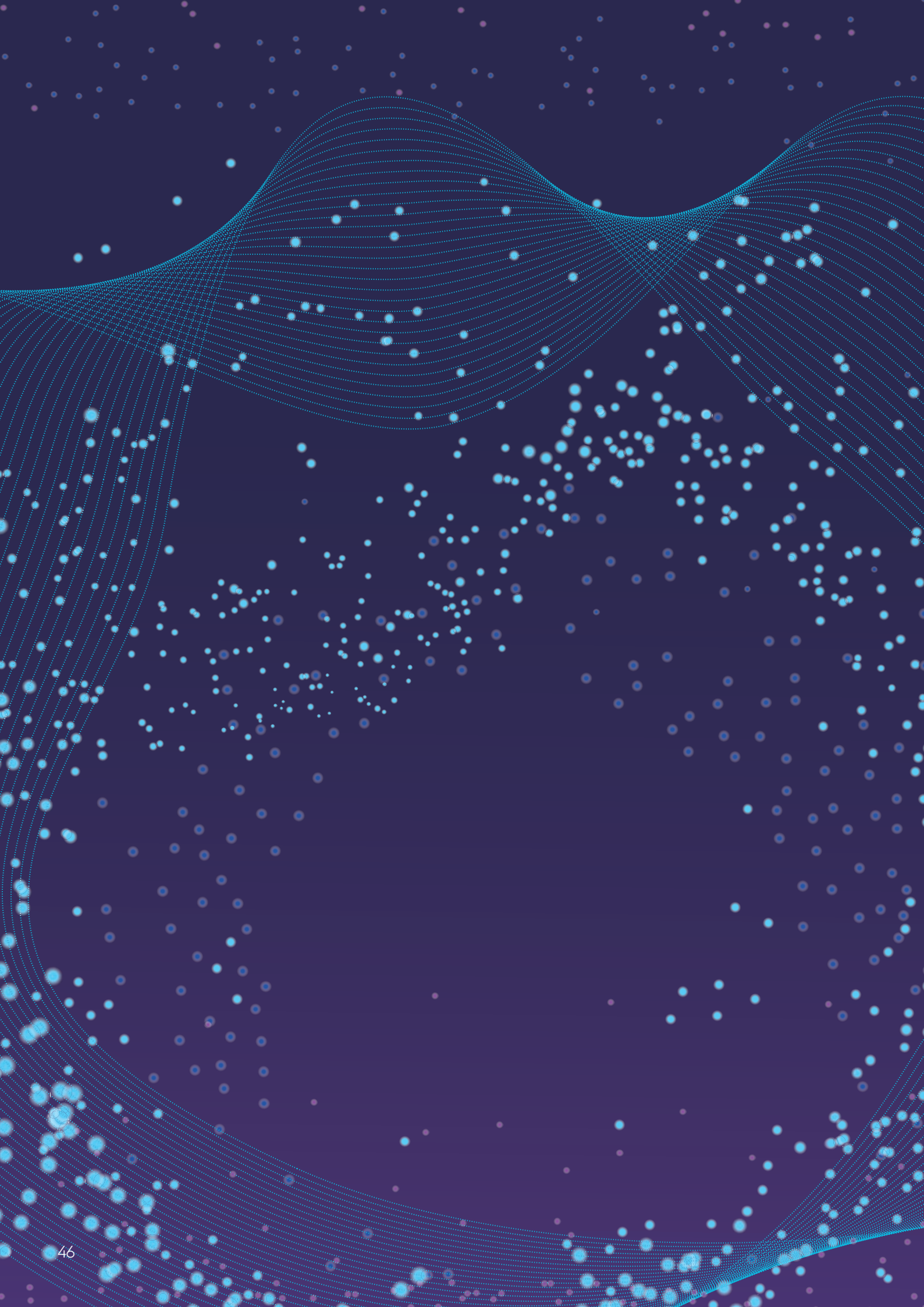
Cybersecurity governance and regional joint defense form the core strategy. Central management coordinates subsidiaries and affiliates to form joint defense teams, establishing threat intelligence sharing and collaboration mechanisms for timely communication and experience sharing.

In addition, by establishing a centralized Security Operations Center (SOC) and SIEM platform with AI-powered monitoring and collaborative reporting, threat intelligence can flow seamlessly across the organization, enabling early detection and prevention to ensure stable operations. In the event of an incident, resources are swiftly integrated to form an Emergency Response Center, creating

a comprehensive defense system of detection, reporting, and coordinated response against increasingly complex and diverse cyber threats.

This strategy has earned international recognition. In 2024, the Group received the Information Security Leadership Award at the Taiwan Corporate Sustainability Awards (TCSA), highlighting its emphasis on cybersecurity resilience and joint defense.

In the face of quantum threats and AI-driven disruption, only proactive investment and upgraded governance can secure the future. In a rapidly changing era, trust must take precedence over compliance, with active risk identification and forward-looking deployment. Cybersecurity is not just defense; it is a source of competitive advantage.





Insights from Our Partners

Bridging academia, industry, and borders, Hon Hai Research Institute collaborates with partners worldwide to explore cutting-edge technologies such as autonomous driving, low-Earth orbit satellites, quantum computing, and AI security. Beyond innovation, these collaborations foster cross-disciplinary talent and build a resilient, forward-looking technology ecosystem that reflects the limitless potential of Taiwan's smart industries in the future.

CityUHK × HHRI

Forging a Seamless Bridge Connecting Industry, Academia, Research, and Applications

The partnership between City University of Hong Kong (CityUHK) and Hon Hai Research Institute (HHRI) began in 2021. Together, both sides not only advanced the real-world application of academic research but also provided authentic testing environments, accelerating talent development and resource integration.

Professor Jianping Wang, Dean of the College of Computing and Chair Professor of Computer Science at CityUHK, notes that HHRI moves beyond short-term project sponsorship to build long-term research partnerships. By creating joint research platforms where both parties jointly identify research topics, they integrate industry needs directly into academic inquiry, ensuring that research directions align with market dynamics.

Additionally, both parties have established a joint supervisory committee that regularly evaluates key performance indicators. This structure ensures research outcomes remain both academically rigorous and commercially relevant. Regular exchanges among engineers foster cross-disciplinary talent fluent in both

market demands and engineering practice, accelerating the path to commercialization.

Synergies through Joint R&D

As the collaboration deepened, CityUHK and HHRI established a Joint Research and Development Center in June 2024. The Center has already yielded powerful synergies with multiple key achievements.

First, in autonomous driving and vehicle-to-infrastructure communication, the Center's self-developed autonomous mini trucks have completed testing at Foxconn's Longhua campus, with stable communication between vehicles and roadside equipment.

Furthermore, in the field of AI, the Center has published numerous papers at top international conferences, including the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), the International Conference on Computer Vision (ICCV), the Association for the Advancement of Artificial Intelligence (AAAI), and the Conference on Neural Information Processing Systems

(NeurIPS). It has also achieved outstanding results in international competitions.

For instance, the ModeSeq algorithm achieved second place in the 2024 CVPR Waymo Motion Prediction Challenge. Professor Shiqi Wang, professor of computer science at CityUHK, explains that in autonomous driving technology, any data latency can lead to serious safety consequences. Therefore, both teams worked to minimize data processing delays while ensuring data quality.

Additionally, BehaviorGPT won the 2024 Waymo Open Dataset Challenge, while QCNet has dominated the Argoverse Multi-Agent Motion Forecasting Competition for two consecutive years.

In cybersecurity, the Center has successfully published papers at four top security conferences. Research published at USENIX Security 2024 identified attack methods targeting autonomous driving trajectory prediction systems. The team's RedRFT and RedTopic frameworks effectively enhance large language model security and are now integrated into FoxBrain, Hon Hai's in-house large language model platform.

In the field of semiconductors and materials, the center used large language models and machine learning to successfully design and synthesize a new high-stability material, CHDA-Bil₅. This material effectively improves ion migration activation energy and enables high-sensitivity response in X-ray detectors.

As for quantum computing, progress is primarily achieved through talent exchanges and joint simulation research, gradually building results that chart a clear path from theoretical exploration to experimental validation.

Setting a New Benchmark for Industry-Academia Collaboration

Working closely with the AI Research Center, Professor Shiqi Wang observes that due to efficient and flexible communication, their collaboration is highly complementary. HHRI, leveraging its corporate background, provides valuable insights from macro-level direction to micro-level algorithms while maintaining a deep understanding of industry needs and frontline application scenarios. On the other hand, CityUHK's research team focuses on algorithm optimization. "It's like the relationship between fish and water," he says.

Looking forward, Professor Wang hopes the Joint Research and Development Center can transcend traditional project collaboration models to establish an innovation ecosystem that seamlessly connects industry, academia, research, and application. He envisions it becoming a birthplace and accelerator for cutting-edge technologies, producing prototypes or patents with industry impact in core areas each year, achieving successful technology transfer and product integration. Both sides also aim to establish joint talent development mechanisms, transforming the Center into a hub for cultivating interdisciplinary talent who understand both technology and industry.

The collaboration between CityUHK and HHRI demonstrates how academic innovation can seamlessly connect with industrial practice and sets a new benchmark for industry-academia co-creation in the technology sector.

NYCU × HHRI × Hong Young Semiconductor

Innovative SiC Circuits Achieve Stable Operation at 300°C

Compound semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) are known for their high efficiency, high breakdown voltage, and ability to withstand extreme temperatures. These materials form the foundation of high-power, energy-efficient technologies that drive electric vehicles, 5G communications, and fast-charging systems. To bridge academia's deep expertise in GaN-based semiconductors with applications and manufacturing resources within the industry, the Hon Hai Research Institute began collaborating in mid-2022 with Associate Professor Tian-Li Wu and his team from the Institute of Electronics at National Yang Ming Chiao Tung University (NYCU).

According to Professor Wu, the Semiconductor Research Center at that time was developing SiC power devices and seeking to enhance its chip-level design and reliability analysis capabilities. His team, already highly experienced in SiC device design and reliability testing, thus became a strong match. The two sides shared a common vision and complementary strengths, laying

the groundwork for a fruitful partnership.

Building a Vertically Integrated SiC R&D Chain

In the early stages, the collaboration focused on material and process reliability. Over time, it expanded to include system-level verification and evolved into a vertically integrated model spanning chip design, reliability testing, and system applications. Within this model, Hong Young Semiconductor, a subsidiary of Hon Hai Technology Group, plays a crucial supporting role.

"This collaboration is a tightly connected three-way partnership," said Professor Wu. "The NYCU team and the Semiconductor Research Center jointly handle device design and circuit layout; Hong Young Semiconductor takes charge of fabrication and process execution; and finally, our NYCU team conducts electrical failure analysis and reliability testing."

After each round of experimentation, the NYCU team and the Semiconductor Research

Center jointly review the test results to identify root causes of problems, plan the next phase of design and process optimization, and provide concrete feedback to Hong Young Semiconductor to drive continuous improvements. In addition, throughout the collaboration, the Semiconductor Research Center regularly contributes system-side and application-oriented insights, enabling the NYCU team to align its design and testing more closely with practical needs and evolving market trends.

Building on a silicon carbide process, the team successfully developed a single-chip integrated circuit technology designed for use in extreme environments. This industry-leading achievement has been officially unveiled and has attracted considerable attention across the industry.

Professor Wu explained that the core advantage of this technology lies in its ability to maintain stable performance at 300°C, thus overcoming the limitations of conventional silicon components. SiC, with its wide bandgap and high thermal conductivity, effectively reduces leakage current and enhances reliability, making it one of the most promising materials for high-temperature, high-power applications.

The collaboration also resulted in other innovative designs. For instance, in circuit architecture, the integration of 4H-SiC MOSFETs with Insulated-Gate Resistor Loads (IGRL) on a single chip enables automatic gain compensation in response to input voltage variations. The result is high linearity, wide output swing, a simplified architecture, and excellent high-frequency stability. Even at 300°C, the circuit maintains MHz-level bandwidth and remains compatible with existing SiC power device fabrication

processes. This breakthrough holds strong potential for mass production and marks a key technological advancement for applications such as automotive electronics, aerospace control systems, and high-temperature sensing.

A Dual-Track Strategy Shaping the Future

“A successful industry-academia collaboration depends on two things: aligned goals and complementary roles,” said Professor Wu. “Innovation alone is not enough. If it doesn’t address real-world needs, it won’t take root. This three-way partnership has not only generated technical results but also created a positive cycle between academic research and industrial practice. That’s what truly drives the industry forward.”

Looking ahead, Wu expressed strong support for the dual-track strategy championed by HHRI: AI for Semiconductor and Semiconductor for AI. The two directions, he explained, reinforce each other. The former applies AI to accelerate semiconductor R&D through process optimization and reliability prediction, while the latter focuses on developing higher-performance, energy-efficient semiconductor devices to meet the immense computational demands of the AI era.

The NYCU team will continue its collaboration with the Hon Hai Research Institute to pursue further breakthroughs. “This dual-track approach not only enhances R&D efficiency,” Wu notes. “It also fosters a new symbiotic ecosystem where AI and semiconductor technologies evolve together. That synergy will define the future of the industry.”

NYCU × HHRI

Pioneering Resilient LEO Satellite Networks

The Industry Academia Innovation School (IAIS) at National Yang Ming Chiao Tung University (NYCU) has collaborated with the Next-generation Communications Research Center since 2021. Professor Kai-Ten Feng, Professor and Chair of the Department of Electronics and Electrical Engineering at NYCU, explains that the university established the IAIS with government support to cultivate semiconductor industry talent and promote co-creation between academia and industry. In pursuit of suitable industry partners, IAIS found an ideal match in the Next-generation Communication Research Center.

Professor Feng points out the differences in research thinking between academia and industry. Academia focuses on forward-looking research, while the industry emphasizes technologies that can be quickly implemented. However, the Hon Hai Research Institute occupies a unique position between academia and traditional industry: it not only emphasizes product development but also invests in the exploration of emerging technologies and evaluates how they might be

applied across future business units. As a result, HHRI and IAIS share a similar mindset, enabling highly fluid and effective communication.

For Professor Feng's team, collaboration with HHRI has inspired a transformation in their research approach. He explains that past academic research often focused on specific technical breakthroughs, such as communication hardware or software innovation, with less attention to the practical application benefits after technology integration. Therefore, he hopes NYCU will not only pursue technical leadership but also view technology implementation as an important research goal.

Opening New Frontiers in Future Communications

The current collaboration focuses on advanced multi-beam technology for low-Earth orbit (LEO) satellite communications. Professor Feng explains that LEO satellites operate at an altitude of approximately 500 kilometers. Compared to geostationary satellites, they

offer higher-speed data transmission, not only effectively complementing terrestrial base station coverage but also enabling seamless global connectivity. This provides critical infrastructure for high-speed communications in applications such as autonomous vehicles and smart cities, while also offering backup communication capabilities when ground-based systems are damaged during emergencies.

Professor Fang emphasizes the technology's significance for the future of communications. To date, it has yielded impressive results, including reducing the required number of satellites by at least 20% and lowering the hardware complexity of communication payloads by over 50%. Most current LEO satellites have limited transmission speeds and rely on wide-beam transmission. To improve transmission rates, the emerging trend is toward narrow, high-speed multi-beam transmission. The challenge lies in how to enable a single satellite to emit dozens or even hundreds of beams while providing precise service to users in different regions.

To address this, NYCU and the Next-generation Communications Research Center, through innovative hardware and software design, reduced frontend hardware complexity on one hand, while developing technology enabling a single antenna array to emit multiple beams on the other. This not only improves transmission efficiency but also mitigates the growing challenges of space debris and inter-satellite signal interference by reducing the total number of satellites needed.

Test Data to Support Academic Research

Apart from technological breakthroughs, the collaboration also provides more sustainable

and efficient solutions for future satellite communications. Professor Feng reflects that academic research institutions typically struggle to obtain first-hand satellite measurement data and usually must rely on simulations. However, HHRI has successfully launched satellites and operates ground receiving stations, enabling it to provide actual measurement data that serves as an invaluable validation platform for academic research.

Moving forward, Professor Feng hopes NYCU and the Next-generation Communications Research Center can continue to deepen their cooperation to advance satellite interconnection, energy efficiency, and self-healing capabilities.

In the area of satellite interconnection, current systems are mostly limited to single-vendor architecture. Future research will explore how to enable effective interconnection among satellites from different manufacturers, creating more open and extensive networks. As for energy consumption and self-healing capabilities, since satellites cannot be recovered after launch, reducing energy consumption and enhancing resilience are critical. The two sides will investigate ways to lower the energy consumption of satellite communication payloads while enabling satellites to self-adjust and self-repair, thereby improving satellite network stability.

"HHRI grants research teams great freedom, allowing both sides to jointly explore long-term and forward-looking research topics," says Professor Feng. "This kind of collaboration not only transforms academic results into real-world applications but also helps build highly resilient communication networks for the future."

Top Universities in Three Continents × HHRI

Charting the Next Frontier of Quantum Computing

“While Taiwan has advantages in semiconductors and communications, it entered the field of quantum computing relatively late. To make up for this gap, we must seek external partners,” explains Dr. Min-Hsiu Hsieh, Director of the Quantum Computing Research Center, as he outlines his motivation for building a global partner ecosystem.

Building an International Collaboration Network

Dr. Hsieh, formerly an associate professor at Sydney Quantum Academy at the University of Technology Sydney, is internationally recognized for his work in quantum error-correcting codes, quantum communication theory, quantum information theory, and quantum machine learning. After HHRI was established in 2020, he returned to Taiwan to serve as the founding director of the Quantum Computing Research Center. Drawing on over two decades of professional networks and academic connections, he continues to exert significant influence in the field.

In Australia, where he has the deepest ties, the Quantum Computing Research Center has forged partnerships with leading universities such as Monash University, the University of Queensland, and the University of Sydney. Additionally, the research center provides funding support to the nonprofit Australian Quantum Software Network, offering project-based grants that enable Australian researchers, postdoctoral fellows, and PhD students to collaborate with the center’s researchers on quantum-related research initiatives.

Beyond Australia, the Quantum Computing Research Center has established a global collaboration network spanning three continents. Partner institutions include the University of Cambridge and the University of Oxford in the U.K., the University of Tokyo in Japan, Nanyang Technological University in Singapore, and Princeton University, the University of Maryland, and Harvard University in the U.S. Virtually all world-class universities at the forefront of quantum research are engaged in collaboration with the Center.

The Center also actively participates in

top international conferences. Dr. Hsieh has served on the steering committees of two premier quantum computing conferences: the Conference on Quantum Information Processing (QIP) and the Conference on the Theory of Quantum Computation, Communication, and Cryptography (TQC). He and the center's researchers also actively participate in the Asian Quantum Information Science Conference (AQIS), thereby enhancing HHRI's influence regionally and globally.

Deepening Collaboration in a Systematic Way

Dr. Hsieh notes that past international collaboration at the Quantum Computing Research Center primarily relied on his personal academic networks, but from 2024 onward, the Center began "systematizing" collaboration. It began allocating dedicated budgets for international collaboration and signing formal contracts with partners, clearly defining research topics and specifying intellectual property rights, patents, and other key provisions. This has resulted in a far more structured approach than traditional academic exchanges.

Such collaborations allow researchers at the Quantum Center to gain insight into the mindsets of top scientists and channel this understanding into elevating their own research.

In addition to overseas collaboration, the Center is also highly active in fostering local partnerships. It participates in the national quantum initiative and has established collaborative relationships with academic institutions, including Academia Sinica, National Taiwan University, National Tsing Hua University, and NYCU. The Center also regularly hosts online seminars, inviting leading overseas scholars to

share their latest findings and bringing cutting-edge knowledge to foster mutual growth across the local quantum research community.

A Critical Pillar for the 3+3 Strategy

For Hon Hai Technology Group's 3+3 strategy, the collaboration network that the Quantum Computing Research Center has built domestically and internationally is equally significant.

Dr. Hsieh explains that the 3+3 strategy encompasses three emerging industries (electric vehicles, robotics, and smart healthcare) and three core technologies (AI, semiconductors, and communications). Quantum computing is key to enhancing computational power and serves as the next-generation foundational technology underpinning all of these domains.

Through international and domestic collaboration, the Center not only addresses Taiwan's gaps in quantum computing and accelerates talent development but, more importantly, also transforms technologies and capabilities generated through these partnerships into actionable resources. In doing so, it serves as a critical pillar supporting the group's 3+3 strategic framework.

Dr. Hsieh hopes that in the future, the Center can continue to bring excellent overseas quantum computing researchers and students to Taiwan while promoting Taiwan's outstanding scholars and research results onto the international stage.

Through global and local collaborations, the Quantum Computing Research Center not only injects new momentum into the Group's 3+3 strategy but also opens a gateway for Taiwan's quantum research to connect with the world.

NYCU × HHRI

Fortifying Cybersecurity in the Age of AI

To address AI-related security challenges in electric autonomous vehicles, Associate Professor Chia-Mu Yu from NYCU's Department of Electronics and Electrical Engineering has partnered with HHRI to examine how adversarial stickers and surface dirt can cause vehicle cameras to misjudge road conditions. As collaboration deepened and given Hon Hai Technology Group's leadership in manufacturing, the research focus gradually shifted toward AI security in smart manufacturing. The goal is to ensure that highly automated production lines and lights-out factories possess the resilience needed to withstand cybersecurity attacks.

Focusing on Three Major Issues

Current joint research between Professor Yu's team and HHRI focuses on three key issues:

1. **Data Poisoning:** Because the training data used in large language models comes from diverse sources, it may contain malicious code from the Internet or code with security vulnerabilities. This can cause the models to

generate unsafe programs.

2. **Code Quality and Security:** AI-generated code varies in quality and may contain vulnerabilities or errors. While human programmers also make mistakes, because AI generates code extremely quickly, more efficient automated detection tools are needed to ensure code security.

3. **AI Hallucinations and Program Errors:** AI language models occasionally hallucinate, producing fictitious content. While this may occur less frequently in code, a more serious problem is AI may generate code that works but contains errors or has security vulnerabilities that malicious attackers could exploit. Therefore, research goals include reducing the proportion of harmful code generated by AI models and developing efficient automated tools to detect errors.

Clear Roles, Precise Solutions

Professor Yu observes that the division of labor in the collaboration with HHRI is very clear. HHRI acts as the "problem setter,"

identifying real-world industry needs and pain points to ensure that research directions address real issues. NYCU's team serves as the "problem solver," extracting specific, feasible research topics from broad issues and developing solutions.

Through regular meetings, NYCU's team also receives direct, timely feedback from Hon Hai business units. Both sides quickly reach consensus on approaches and communication styles, greatly reducing the communication gap often seen in typical industry-academia collaborations.

Professor Yu believes this collaborative model ensures that academic research moves beyond theory. It allows algorithms and systems developed by his team to be tested on Hon Hai's experimental production lines to verify their feasibility and effectiveness, paving the way for real-world applications.

More importantly, collaboration with HHRI provides NYCU's team with industry perspectives unavailable in academia alone.

Professor Yu explains that academic research is often theory-based, while industry collaboration provides direct engagement with the most pressing real-world problems. Moreover, HHRI not only identifies immediate short-term challenges but also alerts academic teams to issues they may face three to five years ahead, ensuring that research truly helps enterprises reduce costs and improve operational efficiency.

Defending Against AI Attacks, Elevating Taiwan's Cybersecurity Standards

"Collaboration with HHRI holds significant demonstration value and has a profound impact on Taiwan's cybersecurity industry,"

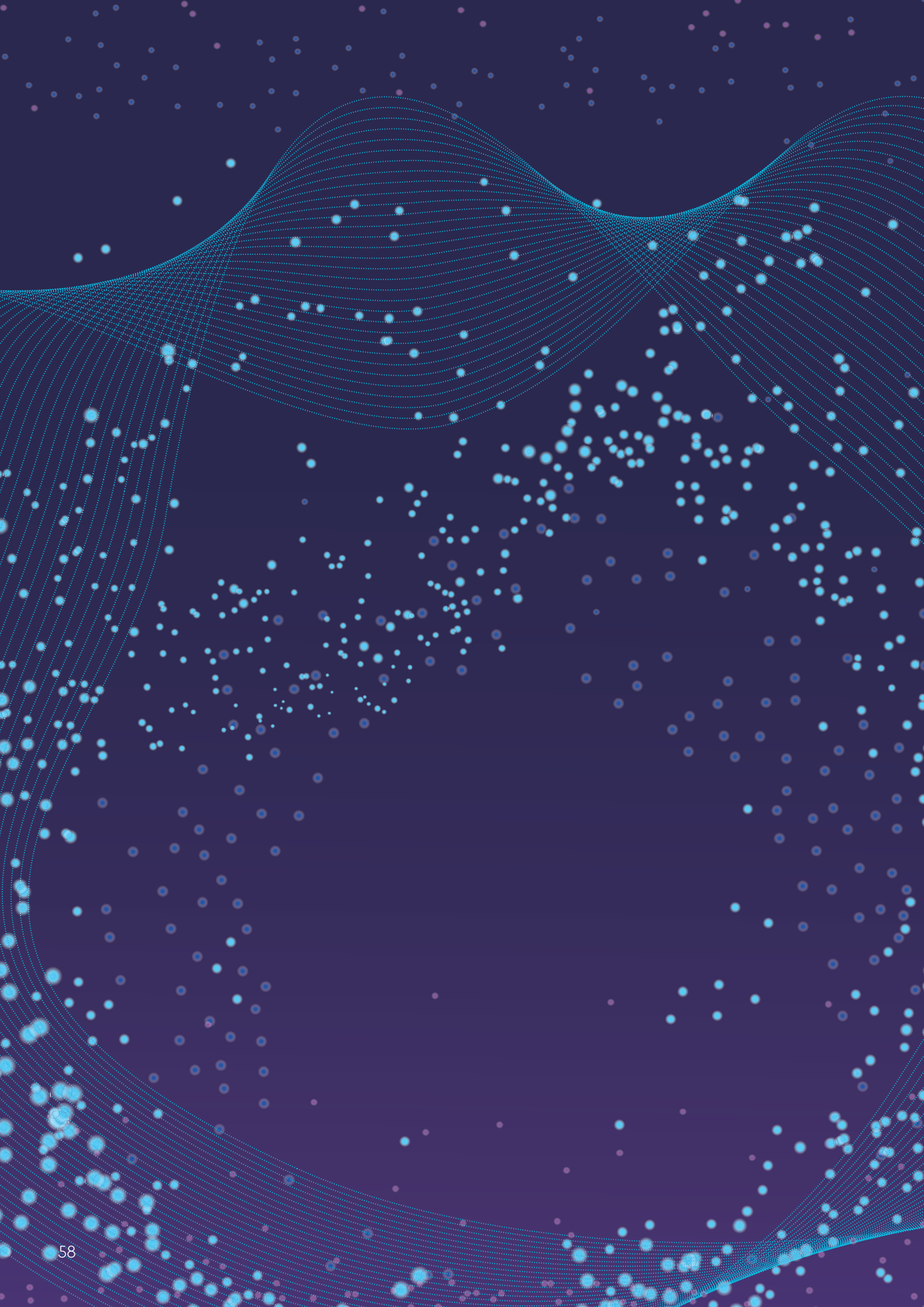


Defensive AI systems strengthen resilience against evolving cybersecurity threats.

says Professor Yu. Currently, most people focus on using AI to solve traditional cybersecurity problems, but NYCU and the Information Security Research Center are already working to defend against attacks targeting AI itself.

He further explains that as AI is widely deployed in electric autonomous vehicles, smart factories, and other fields, hackers no longer target only traditional information systems but are shifting their attention to AI systems. Traditional systems follow program logic, while AI systems involve more complex mathematical algorithms. As a result, attack methods and defensive strategies differ completely between the two.

As tech giants like Google and OpenAI have established AI security teams, Professor Yu believes the NYCU-HHRI collaboration demonstrates to Taiwan's cybersecurity industry that defending AI systems itself is a worthwhile and promising research direction. He hopes this collaboration will encourage more Taiwanese enterprises to invest in cybersecurity, elevating the overall technical standards of the cybersecurity industry.





Moments of Co-Creation

Amid the rapidly evolving tides of technology, Hon Hai Research Institute continues to explore new possibilities with forward-looking vision and deep technical expertise. By bringing together the year's research achievements and innovation milestones, it captures every pivotal moment of co-creation with the world and bears witness to how technology is reshaping human life and industries.

2024 Milestones

▼ 03.13

The Semiconductor Research Center and NYCU developed an innovative facial recognition technology that was featured on the February cover of a leading international journal.

▼ 03.25

HHRI and NYCU co-organized the Industrial Innovation Research Forum.



▼ 03.26

A delegation from the University of Illinois Urbana-Champaign visited HHRI.



▼ 04.22

Award Ceremony for Outstanding Research Papers.



▼ 05.26

A delegation from the Finland Trade Center visited HHRI.

06.20

Established a joint R&D center with City University of Hong Kong (CityUHK) to collaborate on artificial intelligence, semiconductors, next-generation communications, cybersecurity, and quantum computing.



07.04

Mid-year progress review.



07.08

HHRI's quantum research was published in *Physical Review Letters*.

07.23

Hosted the AI NEXt Forum under the theme "Hon Hai at 50: A New Intelligence Era—Generative AI and Future Innovation." The forum featured keynote insights from leading experts both in Taiwan and abroad.



▼ 08.23

The Semiconductor Research Center and National Yang Ming Chiao Tung University (NYCU) published breakthrough research in *Materials Today Advances*, a top-tier materials science journal.

▼ 09.02

- Forward-looking research from the Semiconductor Research Center, conducted in collaboration with NYCU, has been published in *IEEE Transactions on Power Electronics (TPEL)*. The team developed a miniaturized, high-performance advanced LiDAR system.
- A delegation from Australia's Semiconductor Sector Service Bureau (S3B) visited HHRI.



▼ 09.04

Co-hosted the NExT Forum with SEMICON Taiwan to explore applications for next-generation semiconductors.



▼ 09.09

The Artificial Intelligence Research Center and CityUHK co-developed Lite-QCNet, a trajectory prediction model for autonomous driving, which won first place in the Argoverse Challenge at CVPR.

▼ 09.23

The AI Research Center and CityUHK introduced BehaviorGPT, an advanced traffic simulation model, winning first place in the Waymo Sim Agents Challenge.

10.04

The AI Research Center, in partnership with CityUHK, launched ModeSeq, a novel multimodal prediction model.

10.08

Held Hon Hai Technology Day, with HHRI research centers showcasing their cutting-edge technologies.



10.25

The Next-generation Communications Research Center participated in TAITRONICS, AIoT Taiwan, and the Space Industry Supply Chain Development and Communications Talent Empowerment Program.



10.29

The Quantum Computing Research Center and Japan's QunaSys announced a strategic partnership to develop advanced fermionic encoding methods.

11.04

The Quantum Computing Research Center and the University of Cambridge achieved a major breakthrough in port-based quantum teleportation, with results published in *PRX Quantum*.

11.07

Held the Hon Hai Research Institute general assembly.

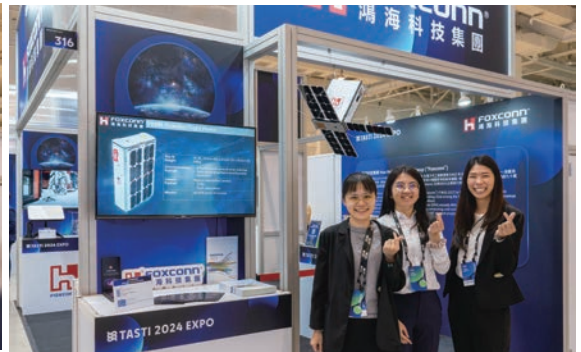


11.20

The Semiconductor Research Center and NYCU won the Future Tech Award for their project "All-GaAs Metasurface Holography for Structured Light & Stereo Vision." The research findings have been published in leading international journals, including *Nano Letters*.

12.01

The Next-generation Communications Research Center presented its latest developments in low-Earth orbit (LEO) satellite communications at the 2024 Taiwan International Assembly of Space Science, Technology, and Industry (TASTI) conference in Taiwan.



12.30

The Semiconductor Research Center and AI Research Center significantly accelerated the R&D process for silicon carbide power semiconductors, with findings published in the *IEEE Open Journal of Power Electronics*.