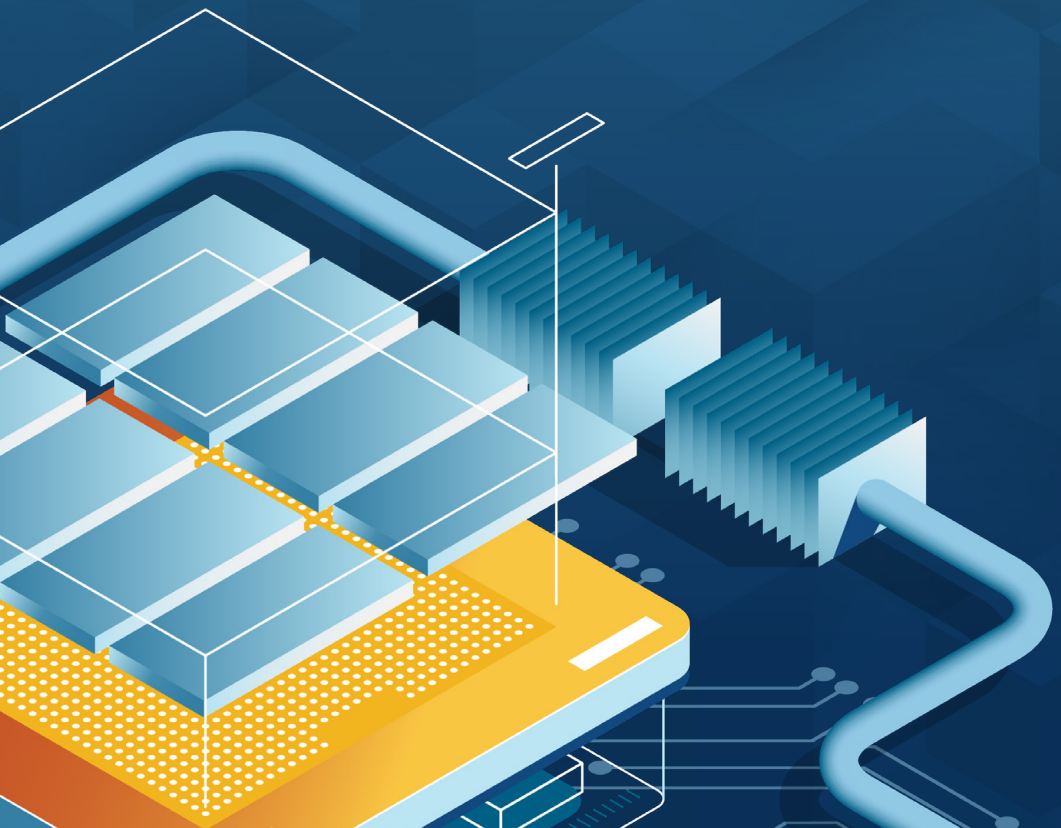
2024

LEADERSHIP SUMMIT FOR ADVANCED PACKAGING

LEADERS ROUNDTABLE REPORT



APPLIED MATERIALS®

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THANK YOU

Dear Valued Partner,

It was a great honor to host our inaugural Leadership Summit for Advanced Packaging on November 19, 2024, in Singapore. During the roundtable, you and your fellow leaders shared many thought-provoking insights, which we have detailed in this report. These insights are crucial as we navigate our industry's challenges and opportunities.

While the most important inflection of our lifetimes is artificial intelligence, the primary barrier to its development is the energy-efficient performance of chips. Simultaneously, our industry faces a looming talent gap. To meet these demands, we must innovate how we innovate—industry-wide, global collaboration is essential to accelerating innovation, commercialization, and workforce development.

Our Equipment and Process Innovation and Commercialization (EPIC) platform addresses this need. The EPIC model fosters deeper collaborations among visionary players across the semiconductor ecosystem, and it provides dedicated space and early access to state-of-the-art equipment.

In 2023, we announced our first initiative: the EPIC Center in Sunnyvale, California, focusing on front-end technologies. As advanced packaging increasingly drives energy-efficient performance, it became clear that we needed to expand our EPIC platform. EPIC Advanced Packaging, anchored in Singapore, will leverage our EPIC model and global network of innovation centers to address the unique technological challenges of advanced packaging while nurturing critical talent.

In line with EPIC Advanced Packaging's mission, our roundtable explored two topics: technology grand challenges, and building talent and capacity. I would like to thank Dr. Raja Swaminathan and Dr. Jun He for facilitating these discussions.

Your perspectives are foundational to identifying our collective priorities at EPIC Advanced Packaging. Moreover, the knowledge we shared and the relationships we built throughout the Leadership Summit are key to fruitful collaborations. I hope you left inspired by the potential of these partnerships. Finally, my paramount takeaway was our group's tremendous excitement for EPIC Advanced Packaging, and its ability to transform the semiconductor industry. Our sustained passion will make our joint vision a reality.

This roundtable has illustrated that in our increasingly connected future, these discussions are vital resources for our industry's success. I look forward to another illuminating dialogue at our 2025 Leadership Summit for Advanced Packaging, taking place in Phoenix, Arizona this coming October. Together, we will continue to shape the future of the semiconductor industry, and technology as a whole.

Until next time,

TERRY LEE
GM / VP Heterogeneous Integration Business Unit
Applied Materials

ROUNDTABLE ATTENDEES

Yeo Yee Chia
Deputy Chief Executive
A*STAR (IME)

Terence Gan
Executive Director
A*STAR (IME)

Sung Jin Kim
Chief Technology Officer
Absolics

Kotaro Hasegawa
Senior Vice President
Advantest

Habib Hichri
Executive Vice President
Ajinomoto

Raja Swaminathan
Corporate Vice President
AMD

Doug Scott
Senior Vice President
Amkor

Peter Wiedner
Senior Vice President
BESI

Keith Tan
Director of Packaging
Broadcom

Jeff Cain
Vice President
Chipletz

Chin Nam Chang
Senior Vice President and Head Semiconductors
EDB

Kaixian Xu
Vice President
EDB

Paul Lindner
Executive Technology Director
EV Group

Beth Yam
Advanced Packaging Factory Manager
Intel Malaysia

Chiaki Takubo
Technology Executive
Kioxia

Aaron Thean
Deputy President and Provost, Professor
NUS

LC Tan
Senior Director
NXP

Hidenori Abe
Executive Director
Resonac

Sangjin Hyun
Executive Vice President
Samsung

Kee Chaing Chua
President
SIT

Woong Sun Lee
Senior Vice President
SK hynix

Bari Biswas
Senior Vice President
Synopsys

Jun He
Vice President
TSMC

William Mackenzie
Senior Executive Officer
Ushio

Masaaki Higashitani
Senior Vice President
Western Digital

Prabu Raja
President, SPG
Applied Materials

Mukund Srinivasan
General Manager
and Vice President
Applied Materials

Satheesh Kuppurao
Group Vice President
Applied Materials

Terrance Lee
General Manager and
Vice President
Applied Materials

Vincent DiCaprio
Vice President
Applied Materials

Len Tedeschi
Appointed Vice President
and General Manager
Applied Materials

Brian Tan
Regional President
and Corporate Vice
President
Applied Materials

Sundar Ramamurthy
General Manager and Group
Vice President
Applied Materials

TECHNOLOGY GRAND CHALLENGES

Dr. Raja Swaminathan, Corporate Vice President of Packaging at AMD, opened the discussion by detailing the urgent need for energy efficiency.

Introduction

Dr. Raja Swaminathan, Corporate Vice President of Packaging at AMD, opened the discussion by detailing the urgent need for energy efficiency. AI is driving tremendous energy demands, with one advanced AI data center requiring as much power as a nuclear power plant. To tackle this challenge, it is essential to enhance energy efficiency at multiple levels: within System on Chips (SoCs), within packages, and beyond. Additionally, manufacturing facilities must adopt a more front-end-like approach to successfully develop these solutions.

There are several methods to improve energy efficiency, especially as our industry further turns to System Technology Co-Optimization (STCO). Dr. Swaminathan outlined four key technological pathways:

- **Reducing energy consumed in data transfer within the package:** This is the most significant factor, with hybrid bonding promising to reduce consumption to less than 0.5 pJ per bit.
- **Reducing energy consumed in signal transmission beyond the package:** This involves minimizing energy use for signals within racks and between racks. It is crucial to consider the industry's transition to photonics, as integrated photonics and electronics promise greater bandwidth and energy efficiency.
- **Larger and higher-performing substrates:** AI chips are growing in size and functionality. Interposers are now four times larger than a single reticle. Substrates must evolve to meet these demands, with sizes expected to increase from 100 mm x 100 mm to 200 mm x 200 mm.
- **Thermal management:** As packages become denser with complex integrations and passive components, increasing power density presents a notable challenge. Therefore, we must create effective power delivery and thermal management solutions.

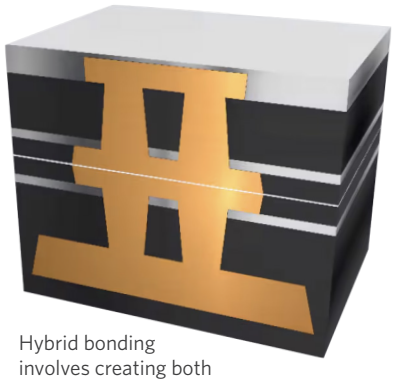
Additionally, Dr. Swaminathan posed two questions:

- Beyond current implementations, what will be the key advanced packaging integrations?
- Where does the silicon fab end and advanced packaging begin?

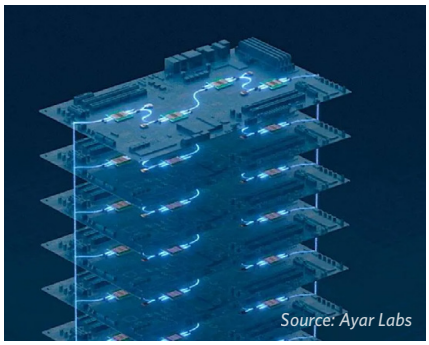
Industry leaders then shared their perspectives on the most pressing technologies, often emphasizing cost considerations and the need for intra-industry collaboration.

Interconnects

Multiple participants highlighted **hybrid bonding** as a critical building block to driving higher-density connections, increased bandwidth, and ultimately, more energy-efficient performance at the system level. Reducing interconnect pitch is essential to increasing interconnect density. Overlay optimization, which ensures precise alignment between dies, is also critical for density, yield, and reliability. Finally, hybrid bonding requires extremely tight process control, such as front-end wafer processing fabs, especially for particle management. However, with numerous manufacturing pathways, the industry must swiftly converge towards a viable and cost-effective approach.



Hybrid bonding involves creating both dielectric-dielectric and direct copper-to-copper bonds between two dies or between a wafer and a die.

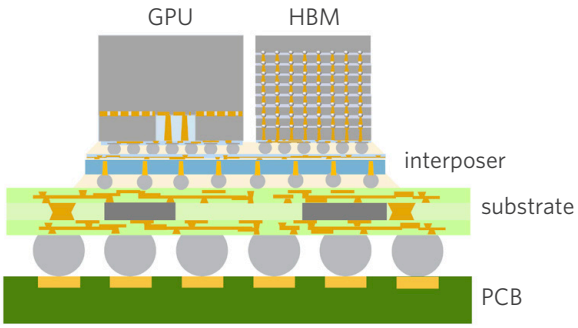


Optical interconnects between a server's blades.

Further, **photonics** promises marked improvement in energy-efficient performance, whether within packages, between packages, or across data racks. Participants are looking to high-density optical interconnects, but this requires more investment to demonstrate feasibility and to examine tradeoffs against conventional interconnects. One leader opined that optimizing the energy consumption of laser systems in optical interconnects is a potential opportunity for enhancing energy efficiency.

Substrates

As chip makers integrate more dies and expand substrate size, warping becomes a greater challenge. To address this, the industry is exploring **new substrate materials**, such as glass substrates, which have superior thermal stability and physical strength. Glass panels additionally enhance performance, improve signal integrity, and enable denser interconnects.



PCB: printed circuit board; GPU: graphical processing unit; HBM: high-bandwidth memory

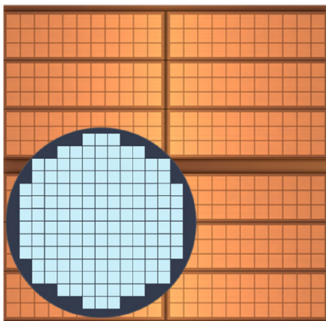
AI Package Requirements	Material Properties	Glass	Organic
Larger Packages	Mechanical stiffness	6x	1x
	Thermal expansion	0.1x	1x
Faster Signal Propagation	Signal Quality Factor	4x	1x

Source: Adapted from Yole Intelligence, *Status of the Advanced IC Substrate Industry 2023*

However, the unique nature of glass substrates requires new approaches to inspection, metrology, handling, processing, and forming interconnects. Innovating and commercializing glass substrates is an interdisciplinary effort. To realize the many opportunities for innovation, ecosystem players must understand each other's viewpoints and coordinate capacities. One participant emphasized the need for substrate players to develop a better understanding of design, and for design companies to develop a better understanding of substrates.

To improve energy-efficient performance and thermal management, new techniques are merging the functions of the substrate, redistribution layer **(RDL)**, and printed circuit board **(PCB)**. These techniques include advanced substrates, cutting-edge interposers, and fan-out wafer-level packaging. As their manufacturing processes become more interconnected, companies must collaborate to produce solutions. One participant underscored the importance of signal integrity continuity from a materials standpoint.

Panels also offer considerable benefits for advanced packages. Compared to circular wafers, their large sizes and rectangular shapes lead to higher material utilization and reduced cost per device. Their properties also allow for double-sided processing, which accommodates more complex RDLs and varying thicknesses, thereby enabling superior thermal management. For one company, cost was the main entry point for investing in panels, but their high performance in AI applications have bolstered their efforts.



Silicon wafer 300mm diameter | Panel 510x515mm

Thermal Management

One leader remarked that thermal management in advanced packages is a major priority for their company. GPUs can generate up to 80 – 90% of heat in a system, and, as transistors shrink in advanced nodes, heat density increases. Thermal management techniques focus on reducing heat generation with energy-efficient transistors and interconnects on dies, incorporating lower resistance interconnects in packages, and efficiently removing waste heat.

One leader mentioned that Silicon Carbide (SiC) power devices could improve energy efficiency and thermal management because they can operate at higher temperatures and frequencies with lower losses. Additionally, Aluminum Nitride (AIN) is a promising candidate for thermal management due to its high thermal conductivity.

Design

For advanced packages, designers must take a single system, integrated approach. Many innovative ideas for 3D design originate from 2D tools used for power optimization. In addition to design, they are essential for analysis, optimization, and sign-off, providing comprehensive STCO tools. Looking ahead, designers require **place-and-route products** that function seamlessly within 3D systems. Additionally, finding the appropriate package design among many integration pathways involves co-optimizing materials and other aspects in the multi-physics domain.

Finally, there is substantial opportunity in integrating **process design kits (PDKs)** and **assembly design kits (ADKs)**. PDKs help optimize the internal design of the chip for the fabrication process. Alternatively, ADKs support package-level design, considering the chip's environment and connections to other components. Currently, these tools are disconnected, and most communication is through PDKs. However, merging the two will enable superior designs and a more efficient design process. This integration requires collaboration across the ecosystem, including materials and equipment players.

Bridging Front-End and Back-End

Several participants called for bridging the divide between front-end and back-end manufacturing processes, which often exist in different facilities and companies. As heterogeneous integration processes become more complex and fragile, front-end and back-end processes become more inter-dependent.

Data generation and sharing are crucial to advancing these processes. For example, creating more tailored machines for advanced packaging requires fabs—who are the experts in manufacturing processes—and equipment suppliers to share data with each other. However, data sharing in the semiconductor industry is complex due to IP considerations. Additionally, the industry should examine leveraging data and advancements in AI for advanced packaging.

Many leaders discussed how back-end manufacturing could incorporate learnings from the front-end, as the front-end roadmap has converged on key technology inflections, especially in memory. This includes data sharing; cost-effective process control, such as for particles and hybrid bonding; and a common metric to measure performance. Like the front-end's ring oscillator, this metric should be relevant to the customer and ensure consistent performance from the development cycle to the final product.

One leader noted that while OSATs are being pushed to be more like front-end for packaging, the economics do not encourage this direction. OSATs are extremely cost sensitive and cannot bear the cost and risk of major R&D investments, so OSATs could strategically leverage EPIC Advanced Packaging. With access to equipment and understanding of best-known methods (BKMs), they can more easily develop new technology for high-volume manufacturing.

> The advanced packaging roadmap is very complicated and confusing. There are so many architectures, materials, and candidates. In the front-end, all of the players are looking at the same goal—the driving force of devices is power, performance and area. It's very clear, and most players use identical technologies. But in packaging, it is so complicated.
>
> **DR. SANGJIN HYUN**
> Executive Vice President
> Samsung Electronics

BUILDING TALENT AND CAPACITY

Dr. Jun He, Vice President of Advanced Packaging Technology and Service at TSMC, introduced the second discussion on building talent and capacity.

Introduction

Dr. Jun He, Vice President of Advanced Packaging Technology and Service at TSMC, introduced the second discussion on building talent and capacity. The statistics are staggering: as the semiconductor industry revenue is expected to grow to more than a trillion dollars by 2030, the industry will require over one million additional skilled workers. Dr. He raised a key question: how can we attract people to work in hardware, particularly in the fab, while so many are drawn to software?

There is also significant opportunity to leverage AI for semiconductor advancements. However, attracting software talent is not enough—they must have data to train AI models. Echoing insights from the previous session, he underscored the importance of data sharing among all ecosystem players.

Additionally, heterogeneous integration is not just about integrating technology components but also about integrating people with different expertise. Dr. He stated that this might be a greater challenge than technological ones. To address it, we must start from the ground up, training people with systems-level thinking in universities.

Leaders then discussed the challenges and strategies for building talent and capacity, emphasizing the urgent need for innovative workforce expansion and interdisciplinary thinking.

Attracting Talent

One participant suggested that the industry adopt a key learning from the COVID-19 pandemic's supply chain disruptions to workforce development: shifting from a 'just-in-time' to a 'just-in-case' approach. This shift requires a proactive, long-term, and collaborative commitment from everyone—individual employees, companies, academia, and governments.

Many leaders called for innovative strategies to attract young talent, often drawing inspiration from the software industry. These approaches might fundamentally differ from those used for current leaders and employees, as young people learn and approach their work differently. Young people seek meaningful work, flexible workstyles, attractive and enjoyable office environments, and competitive compensation. The industry must not only adopt these practices but also incorporate them in its marketing to young people, as industry visibility is minimal. The industry must specifically attract talent interested in working in cleanrooms rather than just office or remote work, a challenge faced globally.

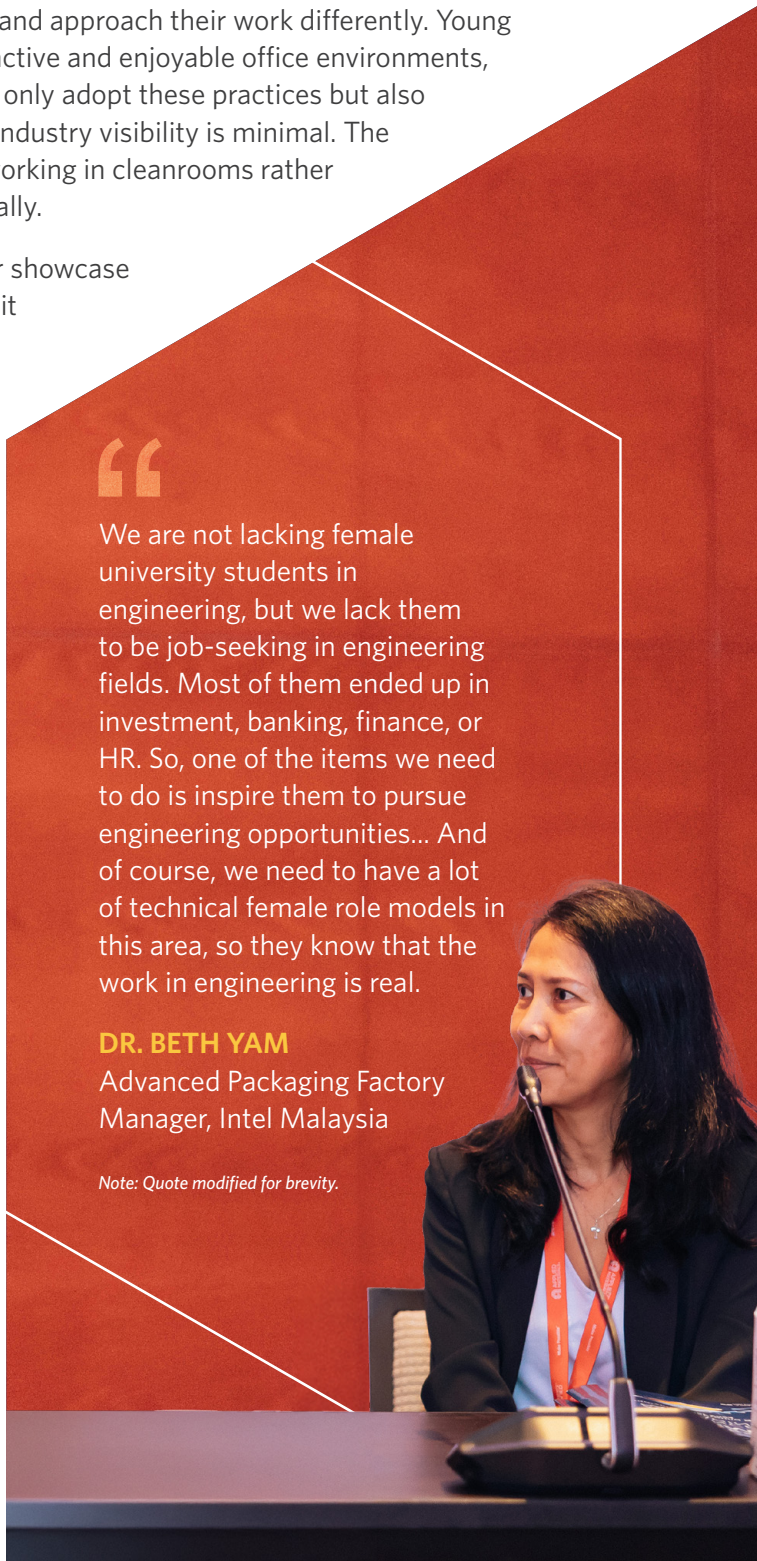
To highlight meaningful work, the industry could better showcase its role in enabling solutions to the climate crisis while it focuses on creating more sustainable manufacturing processes. Additionally, many leaders stressed the need to improve the marketing and brand of the industry—for example, a term like "artificial intelligence" is more appealing to young people than "advanced packaging." Finally, the industry could take more initiative in exposing young people to semiconductors and advanced packaging before university through field trips to cleanrooms, parent and teacher education, social media, and curricular or extracurricular activities.

Given the considerable lack of diversity, the industry should also further promote itself to and facilitate programs for underrepresented minorities. One leader mentioned the importance of creating a stronger pipeline for female talent, lasting from when they enter high school until end of university. Such efforts inspire women to participate in STEM, and then, once they are interested in STEM, to specifically pursue engineering or sciences.

> We are not lacking female university students in engineering, but we lack them to be job-seeking in engineering fields. Most of them ended up in investment, banking, finance, or HR. So, one of the items we need to do is inspire them to pursue engineering opportunities... And of course, we need to have a lot of technical female role models in this area, so they know that the work in engineering is real.

DR. BETH YAM
Advanced Packaging Factory Manager, Intel Malaysia

Note: Quote modified for brevity.



Building Skills

Multiple leaders expressed that curricula should reflect the increasingly interdisciplinary nature of advanced packaging and our industry at large. As machine experts and process experts need to integrate their skillsets further, they need foundational understanding of the larger system.

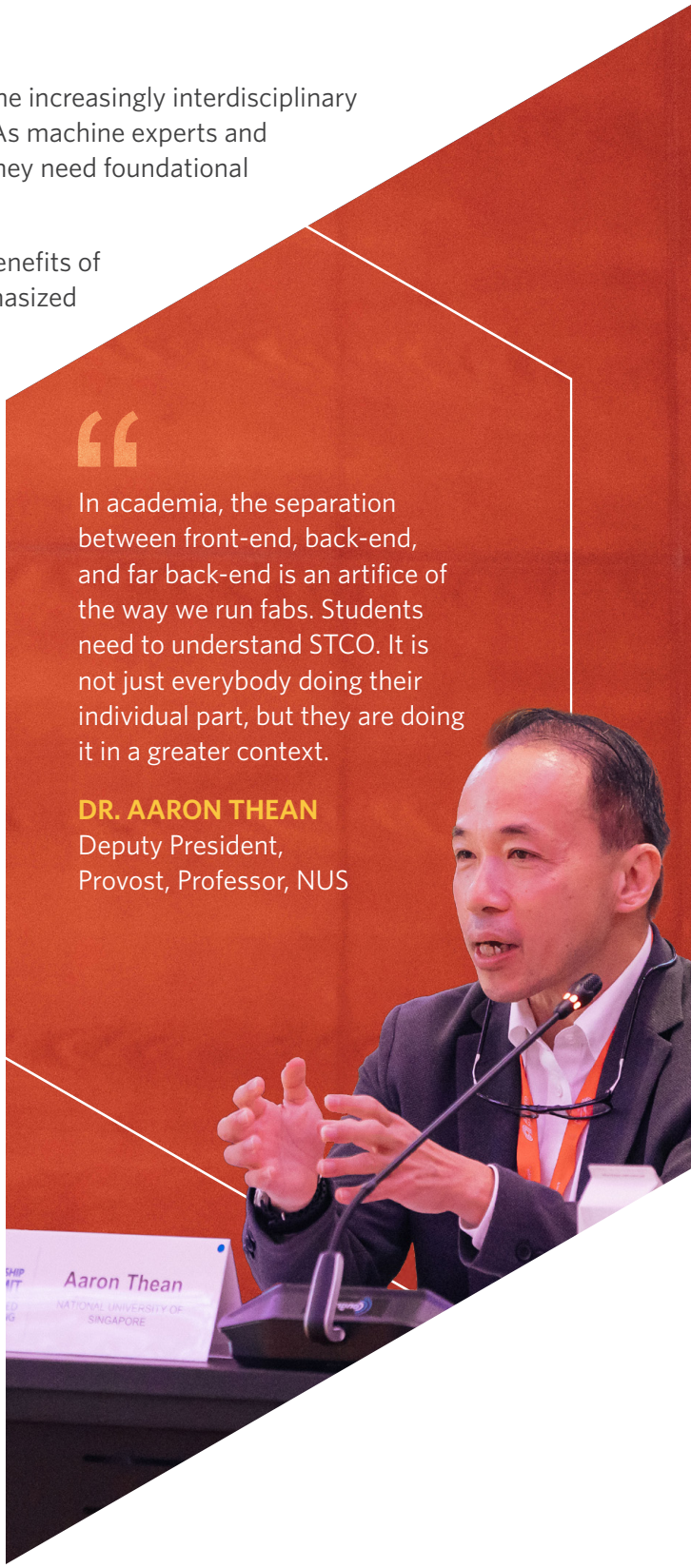
Such systems-level thinking is crucial for unlocking the benefits of data sharing among ecosystem players. One leader emphasized the industry cannot simply share data; we need experts with system-level thinking to properly aggregate data for advanced packages.

To ensure universities are teaching relevant industry skills and knowledge, professors should be included in pioneering research. Co-op programs and extended internships are additional avenues to prepare students for industry and engender interest.

One leader noted that, although predicting the skills students need for the future of advanced packaging is challenging, universities can and should prime students with the skills and passion for life-long learning. Additionally, there are multiple employer initiatives that can facilitate reskilling and upskilling. Some mentioned were sharing data and information between ecosystem players; collaborative, interdisciplinary projects between companies; and stackable modules for curricula.

> In academia, the separation between front-end, back-end, and far back-end is an artifice of the way we run fabs. Students need to understand STCO. It is not just everybody doing their individual part, but they are doing it in a greater context.

DR. AARON THEAN
Deputy President,
Provost, Professor, NUS



IMPLEMENTING EPIC'S VISION

One sentiment was ubiquitous: the industry urgently needs to expand its collaboration, and EPIC Advanced Packaging can play a pivotal role in this effort. In addition to specific technological and workforce challenges, leaders outlined outcomes they envision for EPIC Advanced Packaging:

- Institute a steering committee to further guide strategy.
- Prioritize R&D that is realistic for high-volume manufacturing, considering cost, reliability, and yield.
- Establish an industry common metric for back-end performance.
- Facilitate knowledge sharing between ecosystem players, notably across front-end and back-end.
- Create networking opportunities for serendipitous, inspiring conversation with multiple diverse perspectives. "Aha" moments often happen there.
- Innovate structure for data sharing across the advanced packaging ecosystem.
- Identify ways to attract young talent, such as through industry rebranding or experiential opportunities.
- Connect industry and academia for holistic advanced packaging curricula and training.

CONCLUSION

The inaugural Leadership Summit for Advanced Packaging spotlighted the critical need for industry-wide collaboration to address the challenges and opportunities in advanced packaging. Amid the AI era, the Leaders Roundtable emphasized the importance of energy-efficient performance and the proactive development of a robust, interdisciplinary workforce.

Insights shared by industry leaders on technological grand challenges, such as hybrid bonding, photonics, and thermal management, as well as strategies for building talent and capacity, will guide future efforts. The enthusiasm and commitment demonstrated by all participants illustrate the potential for transformative advancements through EPIC Advanced Packaging.

At the 2024 Leaders Roundtable, we shared our vision for the industry. In 2025, we look forward to outlining the collective action we can take to achieve our goals. By working together, the industry can overcome barriers to innovation and advance towards a more sustainable and efficient future.