Innovation Management

V Achieved ↑ Exceeded — Missed Target

Strategies	2030 Goals	2021 Targets	2020 Achievements	
Technology Leadership Continuous investment in advanced technology development to maintain TSMC's technology leadership in the semiconductor industry	▪ Maintain TSMC's technology leadership and invest **8.5%** of revenue R&D expenses annually	▪ 3nm process technology in risk production	▪ 5nm process technology in volume production **Target:** 5nm process technology in volume production	V
Intellectual Property Protection **Patent protection** Continue to strengthen patent portfolio by keeping patent applications in sync with the Company's R&D resources to make sure that all research achievements are fully protected	▪ Over **50,000** global patent granted	▪ Exceed **5,500** global patent applications	▪ **6,900** global patent applications submitted [Note] **Target:** Over **5,300** global patent applications	↑
Trade secret protection Strengthen business operations and intellectual property innovation through trade secret registration and management which documents and consolidates the TSMC competitive trade secret applications	▪ Over **150,000** trade secret registrations	▪ Exceed **20,000** trade secret registrations	▪ Over **12,000** trade secret registrations **Target:** Over **12,000** trade secret registrations	V

Note : In the wake of adjustments made to the patent portfolio plan for leading technologies, the annual target for 2020 in global patent applications was exceeded, and the long-term goal for 2030 remains unchanged.

Innovation Management Framework

In response to the rapidly evolving semiconductor industry, TSMC has been striving to build an innovative workplace that highly encourages innovation since its establishment. In the face of challenges imposed by competitors and advanced process technology in 2020, TSMC continued to enhance the Company's leading technological competitive advantages through an internal incentive scheme for innovation. Employees are encouraged to bring forth a variety of innovations to enhance organizational innovation vitality. Meanwhile, we also dedicate resources to helping our customers, the industry and academia drive interdisciplinary innovation collaborations, including product innovation with our customers, technical talent innovation with research institutions, and green innovation with our suppliers.

Accumulate Internal Innovation Energy

Idea Forums

- Operations
- R&D
- Quality and Reliability
- Corporate Planning Organization
- Finance

Total Quality Excellence and Innovation Conference (TQE)

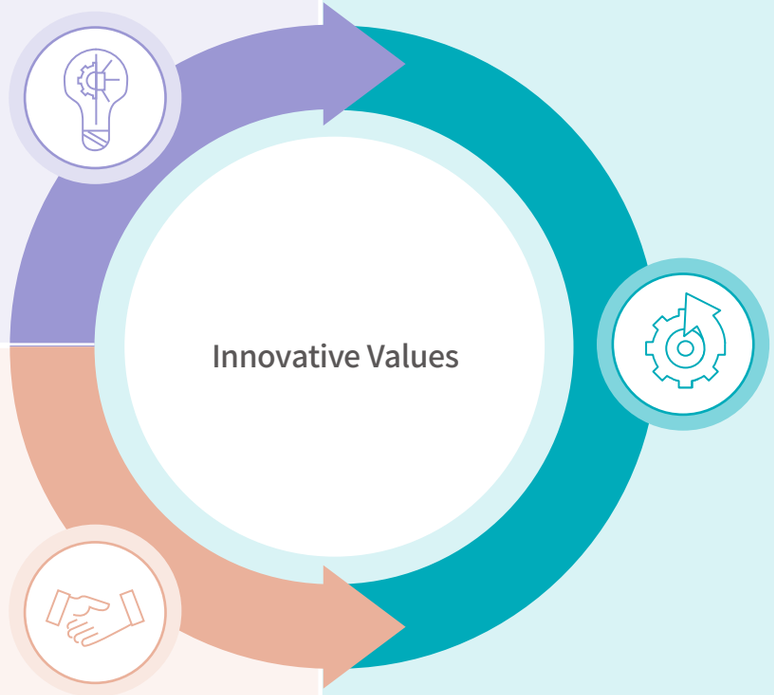
CSR AWARD

Innovate Through Interdisciplinary Collaboration

Open Innovation Platform®

Collaboration with World-class R&D Institutes

- University Research Center
- Industry-Academia Joint Development Project
- Semiconductor Programs
- Ph.D. Scholarship NEW
- Advanced IC Design Program NEW
- University Shuttle Program



Realize Innovation

Technology Leadership

Intellectual Property Protection

Intelligent Precision Manufacturing

Innovation Cases

- Virtual Design Environment (VDE) New Model for Industry-academia Collaboration
- High-Efficiency Hazardous Substance Testing Mechanism
- Smart Technical File Navigation System
- Increasing EUV Energy Efficiency
- Biological Treatment System
- Waste Management with Full Traceability
- Management Mechanism for Stack Emission Baseline

Technology Leadership

In 2020, TSMC continued to expand its scale of research and development. The total R&D expenditure for the year was US$ 3.72 billion, a 26% increase from the previous year and 8.2% of the Company's total revenue[Note1]. The R&D team has grown to a team of 7,404 people, a 13% increase from the previous year. The scale of R&D investments is on par with top tech companies worldwide and even surpasses the scale of some companies.

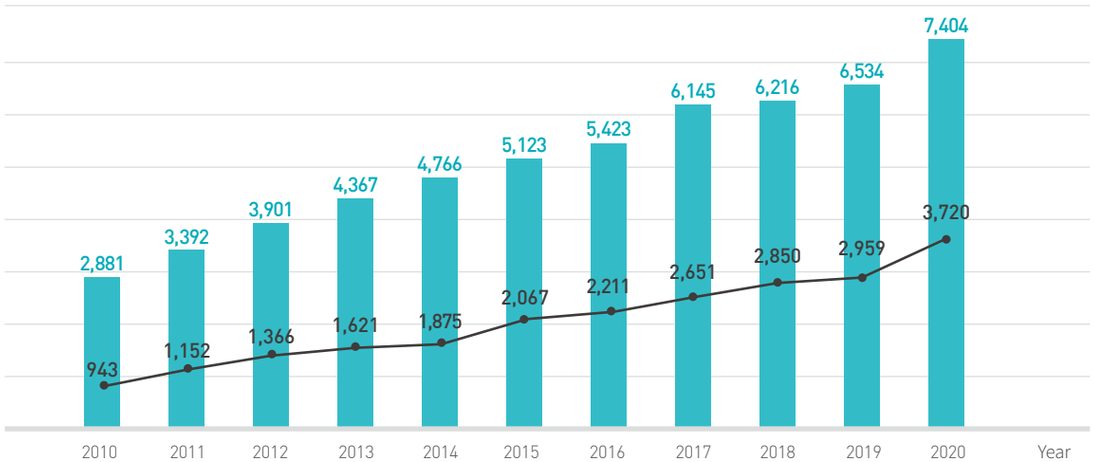
Faced with the increasingly difficult challenge to continue extending Moore's Law, which calls for the doubling of semiconductor computing power every two years, TSMC has focused its R&D efforts on offering customers first-to-market, leading-edge technologies and design solutions that contribute to their product success. In 2020, following the application of 5nm technology to mass production, the Company's R&D organization continued to fuel the pipeline of technological innovation needed to maintain industry leadership. For TSMC's 3nm technology, the sixth generation platform to make use of 3D transistors, TSMC continues full development with major customers and has completed IP design and started silicon validation, the Company's research and pathfinding pushed forward with exploratory studies for nodes beyond 2nm, which is the leading-edge technology in the semiconductor industry today.

In addition to complementary-metal-oxide-semiconductor (CMOS) logic, TSMC conducts R&D on a wide range of other semiconductor technologies that provide the functionalities required by customers for mobile System-on-Chip (SoC) and other applications, such as smartphones, high-performance computing, IoT, and automotive electronics, etc.

In 2020, TSMC maintained its strong partnership with the world's top research institutions, including the Semiconductor Research Corporation (SRC) in the United States and the Interuniversity Microelectronics Centre (IMEC) in Belgium. The Company also continues research collaboration with world-class universities, driving advancement in semiconductor technology and nurturing future talents.

TSMC focuses on offering customers first-to-market, leading-edge technologies and design solutions.

Continuous Investment in R&D



Note 1: As reflected upon the revenue growth in 2020, R&D expenditure is slightly under 8.5% of total revenue.

Specialty Technologies/Interconnect & Packaging Technologies

- **3D IC** — 3D IC and System-on-Integrated Chips (TSMC-SoIC®) Technology
- **InFO** — Advanced Fan-Out and Integrated Fan-Out (InFO) Technology
- **BCD** — Power IC/Bipolar CMOS-DMOS (BCD) Technology
- **MCU** — Embedded Flash Memory/ Emerging Memory Technology
- **CIS** — CMOS Image Sensor Technology

Technology Leadership and Innovation

CMOS Logic Technologies

2018

- N7+ technology entered risk production, the industry's first commercially available EUV (extreme ultraviolet) process technology

2019

- 5nm FinFET technology led the foundry to successfully entered risk production
- 7nm FinFET plus technology entered volume production and led the world to deliver customer products to market in high volume

2020

- Volume production of industry-leading 5nm process technology

Specialty Technologies/Interconnect & Packaging Technologies

2018

- Foundry's first underpanel optical fingerprint sensor technology in production
- Developed an industry's unique 90nm BCD technology offering leading-edge 5-16V power devices and dense logic integration with competitive cost, as the next generation mobile Power Management IC (PMIC) solution
- Volume production launch of new generation CMOS image sensors of sub-micron pixel for mobile applications and development of Ge-on-Si sensor for three dimensional range sensing applications with superior performance
- High-volume production of InFO-PoP Gen-3 for mobile application processor packaging

2019

- The world's first 7nm automotive platform
- Completed process validation for System on Integrated Chips (SoIC®), an innovative wafer-level package technology
- Achieved High-volume production of Gen-4 Integrated Fan-Out Package on Package (InFO-PoP) for mobile processor packaging
- Successful qualification of Gen-5 InFO-PoP advanced packaging technology for mobile applications and Gen-2 Integrated Fan-Out on Substrate (InFO-oS) for HPC applications
- Developed 40nm BCD (Bipolar-CMOS-DMOS) technology–unique in the industry–offering leading-edge 20-24V HV devices with full compatibility to 40nm ultra-low-power platform and integration of RRAM, in turn, enabling low power, high integration and small footprint for high-speed communication interface in mobile applications
- Developed 28nm eFlash for high-performance mobile computing and high performance low-leakage platforms, which achieved technical qualification for automobile electronics and micro controller units (MCU)
- Developed the latest generation CMOS image sensors of sub-micron pixel for mobile applications and embedded 3D metal-insulator-metal (MiM) high-density capacitors for global shutter and high dynamic-range sensor applications

2020

- Accomplished process validation of SoIC® for both chip-on-wafer (CoW) and wafer-on-wafer (WoW) stacking using micron-level bonding-pitch processes with promising electrical yield and reliability results
- Entered high-volume manufacturing of InFO-PoP Gen-5 packaging for mobile application processors and successfully qualified InFO-PoP Gen-6 for mobile applications with enhanced thermal performance
- Developed InFO-oS Gen-3, which provides more chip partition integration with larger package size and higher bandwidth
- Expanded the 12-inch BCD technology portfolio on 90nm, 55nm and 22nm in 2020, targeting a variety of fast-growing applications for mobile power management ICs with various levels of integration
- Achieved technical qualification of 28nm eFlash to support automobile electronics and microcontroller units (MCU) applications
- Began production of 28nm RRAM technology as a low-cost solution to support the price-sensitive IoT market
- Achieved technical qualification of 22nm MRAM technology to successfully volume-produce MRAM and received the Flash Memory Summit 2020's Best of Show award for the most innovative AI application
- Entered volume production of CMOS image sensors technology, with shrunk sub-micron pixel size and sensors meeting automotive grade reliability compliance

Applications		
5nm Fin Field-Effect Transistor (FinFET) (N5) technology 5G mobile communications · High-performance computing	TSMC's most advanced technology that leads in both technology and production capacity, enabling revolutionary products in 2020.	Lead the industry to deliver most advanced products
7nm FinFET (N7) family technologies 5G mobile communications · High-performance computing · Artificial intelligence · Automotive electronics	N7 technology began volume production in April of 2018. By the end of 2020, TSMC has used N7 family technologies to produce more than one billion fully functional and defect-free chips for products to over 100 customers.	Introduce products with industry-leading performances and energy efficiency
N12e™ technology AI-enabled Internet of Things (IoT) edge computing products with high performance and high energy efficiency	Based on 12FFC+ technology and its IP ecosystem, TSMC introduced N12e™ technology in 2020, bringing TSMC's world-class FinFET transistor technology to AI-enabled Internet of Things (IoT) and other high-efficiency, high-performance edge devices. This technology offers industry-leading low operating power (Vdd), and excellent low leakage performance of ultra-low-leakage (ULL) SRAM (static random access memory), and new ultra-low leakage devices.	Introduce edge AI-products with industry-leading power saving to prolong battery life of such products
22nm Ultra-low Leakage (ULL) (22ULL) analog technology Smartphones · AI-enabled IoT applications	22ULL analog technology platform, which is fully compatible with logical process, was established in 2020. This platform offers low-noise 2.5-volt input/output (IO) transistors and low temperature-coefficient-of-resistance (TCR) TaN (Tantalum nitride) thin film resistors to support customers' differentiated analog designs.	Introduce products with differentiated analog designs
22ULL Radio Frequency (RF) (22ULL RF) technology 4G RF · Wireless connectivity to IoT	22ULL RF technology received product tape-outs from over 20 customers in 2020.	Introduce products with industry-leading RF performances and cost-effectiveness
22ULL Embedded Magnetic Random Access Memory (MRAM) technology Wearable devices · IoT microcontroller unit (IoT MCU)	22ULL Embedded MRAM technology IPs completed reliability qualifications in 2020, with >100K cycle endurance and reflow capability. This technology demonstrated automotive Grade-1 capability and was applied to volume production for customer wearable products in 2020.	Introduce leading energy-efficient MCU to extend battery life for wearables
CMOS Image Sensor (CIS) technology Smartphones	In 2020, TSMC helped customers lead the market in rolling out 0.8μm pixel products. Pixel size was further reduced to 0.7μm within nine months with timely volume production. The smaller pixel size enables 30% higher resolution for CIS with the same chip size.	Lead the industry to deliver most advanced products
CMOS MEMS (micro electro-mechanical systems) technology Medical devices	TSMC successfully helped customers bring monolithic ultrasonic scanners into volume production.	Lead the industry to produce innovative, high-performance and portable ultrasonic scanners at affordable low prices to better human health and living
3DFabric™ technologies 5G mobile devices · High-performance computing applications	In 2020, TSMC introduced 3DFabric™, a comprehensive family of 3D silicon stacking and advanced packaging technologies, which are comprised of frontend TSMC-SoIC™ 3D silicon stacking and backend 3D interconnect technologies which include CoWoS® (chip on wafer on substrate) and InFO (integrated fan-out), providing customers flexible solutions for integration of chiplets.	Introduce products with industry-leading performances and energy efficiency
InFO-PoP (Integrated Fan-Out Package-on-Package) technology Advanced mobile device applications	Successfully developed InFO-PoP technology, which integrates 5nm SoC (System-on-Chip) and DRAM (dynamic random access memory) for advanced mobile device applications. This technology helped deliver several customer products to market in high volume in 2020.	Introduce products with industry-leading performances and battery life

TSMC Continues to Advance Technologies to Unleash Customer Innovation

Semiconductors are transforming many key industries, including information and communication, transportation, education, health care, entertainment, agriculture, etc. because of their greater capabilities and better energy efficiency through innovations and breakthroughs. These advancements are critical to the future of electronics that will bring more positive impacts on our lives. As the most trusted dedicated foundry service provider in the world, TSMC continues to deliver industry-leading, next-generation, leading-edge semiconductor technologies, as well as offer comprehensive specialty technologies and leading 3D chip stacking and packaging services to help customers unleash their innovations and deliver more advanced, more capable, more energy-efficient, and more affordable products, including smartphones, high performance computing (HPC), Internet of Things (IoT), automotive, digital consumer electronics, health care devices, etc.

Collaborate with Customer to Deliver World's First Handheld, Single-probe, Whole-body Ultrasound System that Helps Improve Overall Healthcare System Efficiency

One remarkable example was our collaboration with Butterfly Network, which delivered its next-generation Butterfly iQ+, the world's only handheld, single-probe, whole-body ultrasound system in 2020, following the debut of its initial model, Butterfly iQ in 2018. By delivering groundbreaking performance and unparalleled efficiency with faster, sharper, and more detailed imaging, the Butterfly iQ+ helps healthcare providers around the world save time during diagnosis and treatment of patients to improve overall patient outcomes. Leveraging Butterfly Network's most advanced Ultrasound-on-Chip™ technology and TSMC's world-leading CMOS MEMS manufacturing technology, the ultrasound transducers can be seamlessly integrated on a single chip. The Butterfly iQ+ features 15% faster frame rates and 60% faster pulse repetition frequency, to give healthcare practitioners the clarity they need to help get important insights quickly.

In addition, the Butterfly iQ+ extends battery life by 20% and scanning time by 100% to enhance operation efficiency. The high-performance imaging capabilities and excellent operation efficiency make this innovative product a powerful tool to help healthcare providers around the world to make timely diagnosis and decisions for treatment, even if they are in underserved communities or in remote areas. Additionally, the innovative Butterfly IQ+ has been shown to be a particularly useful tool during the global COVID-19 pandemic due to its lung imaging capabilities, portability and ease of cleaning, as infection control has become increasingly important. The Butterfly iQ+ marks a big step forward for point-of-care ultrasound with its innovations and breakthroughs, and will continue to bring significant clinical, economic and societal impact going forward.

In total, TSMC deployed 281 distinct process technologies, and manufactured 11,617 products for 510 customers in 2020 to continue to bring significant contribution to the advancement of modern society.

Butterfly Network Collaborates with TSMC to Unleash Innovation to Help Improve Patient Outcomes and Efficiency across Global Healthcare Systems

Butterfly™ iQ+

IC Product

- Butterfly Network delivers new-generation Butterfly iQ+, an innovative handheld, single-probe, whole-body ultrasound system

Product Innovation & Breakthrough

- Butterfly Network puts ultrasound on a single chip with its most advanced Ultrasound-on-Chip™ technology
- The Butterfly iQ+ features 15% faster frame rates and 60% faster pulse repetition frequency to deliver sharp imaging
- The Butterfly iQ+ extends battery life by 20% and scanning time by 100% to enhance operation efficiency

Impact on Society

- By delivering groundbreaking performance with fast, sharp imaging and unparalleled efficiency, the Butterfly iQ+ can help healthcare providers around the globe save time in their diagnosis and treatment of patients, improving overall patient outcomes

Butterfly Network collaborates with TSMC to deliver its new-generation Butterfly iQ+, the world's first handheld, single-probe, whole-body ultrasound system that helps improve patient outcomes and efficiency across global healthcare systems
Photo: Courtesy of Butterfly Network

TSMC's Role

- Provide world-leading CMOS MEMS manufacturing technology to enable integration of the ultrasound transducers on a single chip
- Dedicate a professional engineering team to help Butterfly Network unleash this product innovation

Intellectual Property Protection

TSMC constructs a global strategic patent portfolio to secure freedom in business operations, strengthen leadership in the industry, and protect R&D results in leading-edge technologies. Based on the Company's technology leadership in professional semiconductor manufacturing, the global intellectual property portfolio strategies combined with innovative analysis methods of patent map navigation, the battle-tested patents created through invention mining from R&D technology blueprints to seize the commanding heights in key technologies, TSMC generates more patents with higher R&D investment output rate in the industry. Meanwhile, under an innovative patent management mechanism, patent prosecution processes are closely monitored to ensure quality and efficiency. The Company reviews patent portfolio regularly, as well as acquiring patents strategically and/or collaborating with patent alliance(s), to build a comprehensive patent protection network.

Global Patent Portfolio Strategies

- Ensure freedom in global operations
- Protect leadership in innovative technologies
- Strengthen overall market competitiveness
- Establish exceptional IP reputation in the industry

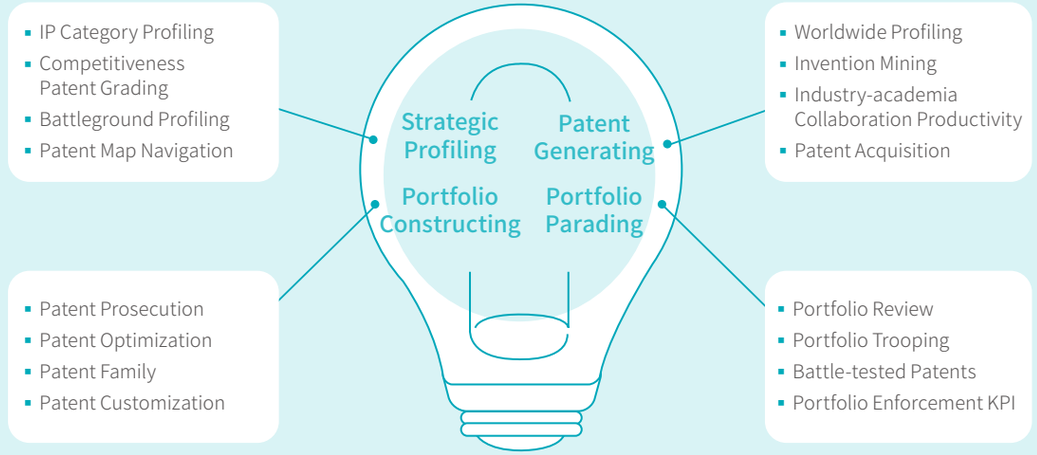
Build Global Strategic Patent Portfolio

TSMC's number of patent published applications in the U.S. ranked third in 2020, setting a new record in history. The number of patents issued in the U.S. ranked sixth on the list, same as the ranking of patent grants in 2018, the historical record. TSMC also ranks first among the top ten patent holders in the U.S. in terms of patent approval rate. The number of global patent grants accumulated has reached 45,000, and 27,000 of which were the contributions of 73 recognized TSMC Prolific Inventors. Meanwhile, TSMC encourages employees to file their inventions for patent applications. In 2020, 459 employees contributed for the first time to a total of 387 U.S. patents.

Four Initiatives of Patent Management Mechanism

TSMC implements four IP management initiatives under an all-around patent management mechanism to protect the Company's R&D results and technology leadership. The initiatives include strategic patent profiling, competitive mining and generating, portfolio construction, and portfolio parading.

TSMC's all-around patent management mechanism involves a review mechanism, reward system, promotion education, and talent training programs. The Company has established a grading mechanism for patent prosecutions that reviews invention disclosures, manages entire patent application process, and expands patent families. It maximizes existing resources to generate a highly strategic patent portfolio that has significant global influence. Meanwhile, TSMC employees are encouraged to continuously file their inventions through diversifying innovation-driven mechanisms.



Patent Achievements with Quality and Quantity in 2020

Patent Applications

- 6,900 global patent applications, including over 3,500 U.S. patent applications
- Ranked 3rd in most U.S. patent published applications, setting a new record
- Ranked 1st in patent published applications in Taiwan for five consecutive years

Patents Granted

- Nearly 4,600 global patent grants, including over 2,800 U.S. patents
- Ranked 6th in patent grants in the U.S. at a record-high, same as the ranking in 2018
- Ranked 1st in patent grants in Taiwan

Patent Quality

- Highest patent approval rate at 99% among the Top 10 U.S. patent holders

In 2020, the annual TSMC Patent Campaign successfully attracted nearly 1,400 entries of inventions, and about 3,000 employees joined the Online Quiz on patent knowledge. Meanwhile, the cross-function Leading Technology Invention Forum held eight forums to discuss six emerging technologies and received more than 700 inventions.

TSMC also proactively maintains close ties with both domestic and international patent offices through technical exchanges, assisting patent examiners in better understanding the technical content of TSMC, and consequently accelerating the patent examination process in order to obtain high-quality patent protection. In 2020, TSMC was invited to share the Company's experiences in IP management in four industry-government-academia IP seminars, contributing to the widespread of IP education and talent cultivation, and facilitating an upgrade in IP protection. Meanwhile, TSMC also shares practical experiences and insightful advice on patent mechanisms and reviews efficiency to help build a comprehensive IP protection mechanism.

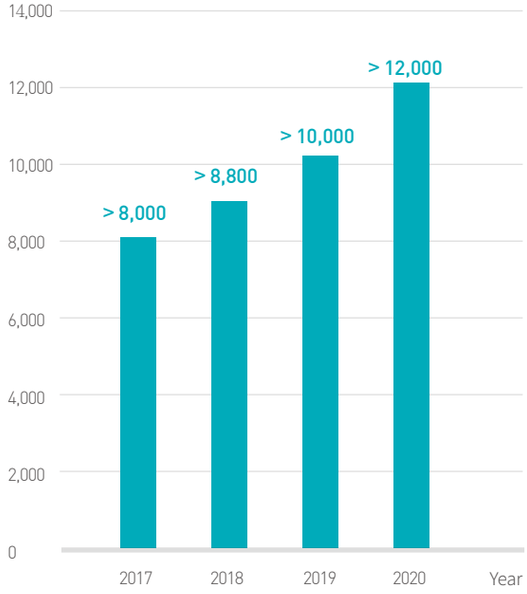
Trade Secret Protection

TSMC's stable core business is the foundation in fulfilling its corporate social responsibility. As TSMC's most important intellectual property, trade secrets are not only vital to TSMC's competitiveness, but also the driving force behind its sustainable innovation. Therefore, TSMC built up the Trade Secret Registration and Management System to record and track trade secrets that contribute to the Company's technology leadership, manufacturing excellence, and customer trust. As of December 2020, over 100,000 trade secrets have been registered and recorded by more than 30,000 employees in the system.

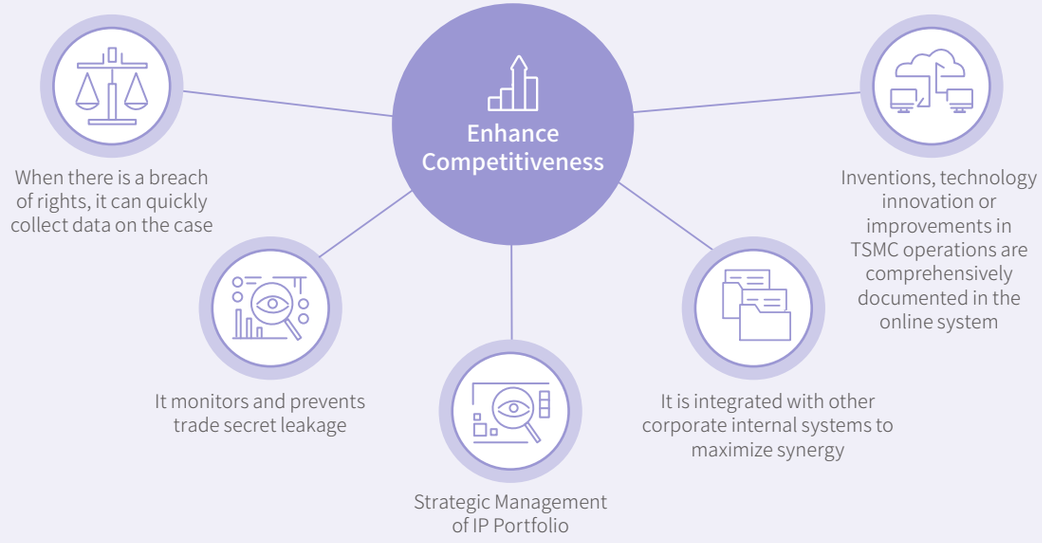
TSMC proactively and systematically manages its key trade secrets as formatted records. Adhering to its culture of innovation and attitude of pursuing excellence, TSMC constantly improves its Trade Secret Registration and Management System by actively applying artificial intelligence technology to keep up with the updates in technology trends and clusters. The Company also established a talent pool to maximize the operational efficiency and benefits of this Trade Secret Registration and Management System for sustainable technology innovation and strengthened overall competitiveness.

TSMC is fully committed to continuously enhance trade secret management to maintain an innovative culture. To recognize employees for their outstanding contributions to the Company, TSMC presents the "Golden Trade Secret Award" every year to registered trade secrets that have the most significant impact on company competitiveness. As of 2020, TSMC has presented 1,616 Golden Trade Secret Awards to more than 4,000 inventors. In 2020, TSMC Chairman Dr. Mark Liu conferred special awards in appreciation of the talented inventors who have earned numerous awards and honors throughout the past six years.

Number of Trade Secrets Registered Each Year



Benefits of the Trade Secret Registration and Management System



Intelligent Trade Secret Management System Powered by Intelligent Automation and AI

Integrated with Human Resources System Integration

TSMC's trade secret registration system integrates with the human resources system and automatically updates employees' registration information in its human resources file. This serves to highlight employees' contributions to TSMC's technological innovations and serve as an important indicator for supervisors to consider for performance evaluation and promotion

Intelligent Reminder Function

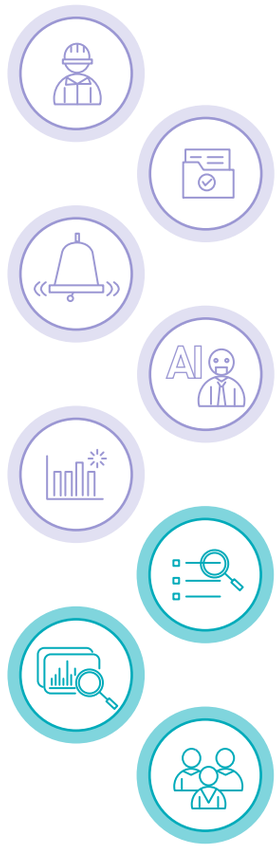
The trade secret system automatically compares employees' trade secret registration records, and reminds them to complete the registration process in a timely manner

Real-time Data Visualization Analysis

TSMC systems uses advanced information analysis software to visualize trade secret registration data and provide employees with real-time updates and precise data on the quantity of registrations, allowing them to more effectively understand their registration status and adjust their registration strategies more efficiently

Technology Cluster NEW

Systematically categorize and annotate registered cases with technology family relation to identify technology clusters



Connected to Contract Management System

TSMC's trade secret registration system is connected to its contract management system, reminding the employees involved in technology development and transfer to register the relevant trade secrets in a timely fashion

AI Chatbot Support

TSMC's trade secret AI chatbot works 24/7 to provide instant replies to support employee trade secret registration and protection queries, thereby enhancing employee trade secret competency

Keyword Analysis NEW

Analyze keywords from previous trade secret registration data to compile and uncover technology development trends

Talent Pool NEW

Analyze Golden Trade Secret award winners' backgrounds to generate an"elite innovation talent pool" for TSMC's talent development planning and strategic management

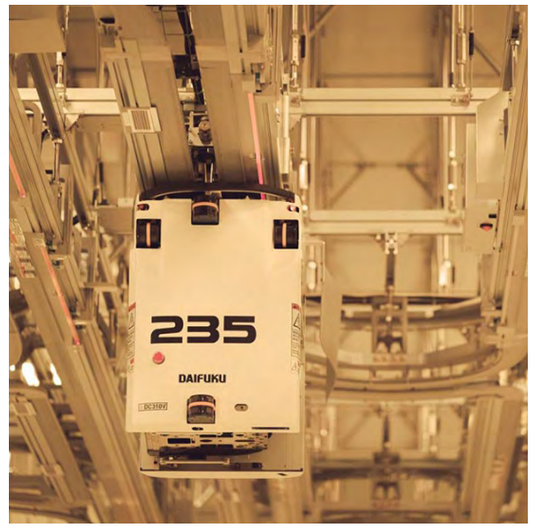
Intelligent Precision Manufacturing

As the world's leading semiconductor foundry service provider, TSMC is the first to realize automated manufacturing. The Company has applied AI to the big data and machine learning platform for wafer fabrication to create an intelligent manufacturing environment featuring self-diagnosis and self-feedback capabilities. In response to the increasingly diversified and growing need for high-quality chips, TSMC initiated a comprehensive digital transformation. Digitized fabs are launched to transform the manufacturing process. With automated data collection, system assistance and AI judgment, process efficiency per batch is increased by 30% to 40%. In accelerating intelligent manufacturing, TSMC has also built an AI quality control system for wafer fabs to ensure production quality, facilitate benchmarking among different fabs, and strengthen technology transfer capacity.

In intelligent manufacturing, TSMC introduced augmented reality (AR) and mixed reality (MR) technologies to enable cross-fab collaboration remotely. In 2020, iWorker, a remote work system was further adopted to enhance remote access management and internet traffic control. The system allows for over 2,000 employees to work from home simultaneously during peak hours in one day, which is a timely solution to limited access to regular workplaces as a result of the COVID-19 pandemic.

Since TSMC first introduced automated transport and overhead hoist transfer (OHT) systems to 8-inch fabs in 2019 along with the demand forecasting and dispatch system, automated transport per day has exceeded 150,000 times as of December 2020. By providing a safe and friendly work environment, the systems help more than 3,000 employees increase work efficiency by 10 to 15%. The adoption effectively increases productivity and reduces risks of ergonomic injuries resulting from the handling of heavy objects.

Armed with intelligent precision manufacturing technology, TSMC is expected to move towards intelligent assistive manufacturing and switch to fully automated intelligent manufacturing TSMC will continue to inject innovation vitality into the global IC industry and be a trusted, long-term partner with our customers.



TSMC led the semiconductor industry by realizing automated manufacturing.

Timeline of Intelligent Precision Manufacturing

2000
- First automated 12-inch GIGAFAB® facilities in the industry built
- 100% automated wafer fabrication achieved

2010
- Computer Integrated Manufacturing system established to integrate highly repetitive and inefficient work
- Productivity of employees at mature manufacturing process facilities increased by 10% to 15% annually

2011
- Wafer Big Data Infrastructure constructed
- Analysis results produced by artificial intelligence introduced to the manufacturing system

2013-2016
- Big Data Analytics for Semiconductor Manufacturing Contest held for three consecutive years in collaboration with MoST and NTHU, with 300 teams from 50 universities
- Big data courses collaborated and improved together with NTU, NTHU, and NCTU, providing both theoretical and practical teaching in class

2017
- Machine learning development platform constructed to accelerate development and expand scale of application
- A program to cultivate 300 machine learning experts launched

2018
- Research pool consisting of 1,000 IT experts and 300 machine learning experts recruited
- Efforts to develop advanced technologies and potential applications through the intelligent system continued

2019
- Engaged experts and professionals in the development of an AI model that integrates human knowledge and computer AI
- Conducted interdisciplinary exchanges with Harvard University, University of Cincinnati, and Ohio State University on the latest AI applications and development in semiconductor manufacturing

2020
- In response to the COVID-19 pandemic, TSMC ramps up digital transformation, using AR and MR technology to enable cross-fab remote collaboration and strengthen inter-fab technology transfer capacity.
- Initiated digitized fabs to transform the manufacturing process, effectively increasing process efficiency by 40%

Year 2000 | 2010 | 2011 | 2013-2016 | 2017 | 2018 | 2019 | 2020

Automation Launched | Enhanced Automation | Intelligent Manufacturing Launched | Cross-field Talent Cultivation | Enhanced Intelligent System | Enhanced Intelligent Pool | AI and Knowledge Integration | Digital Transformation

Automated Manufacturing
- Equipment Automation
- Material Transfer Automation
- Wafer Dispatching Automation

Intelligent Manufacturing
- Wafer Big Data Infrastructure
- Integrated Data Platform
- High-performance Computing
- Machine Learning Platform
- Experts Take Part in Intelligent Model Development
- Expert Knowledge Base
  - Target Analysis
  - Manufacturing Process Characteristics
  - Process Interdependence
  - Data Preprocessing
- Intelligent Scheduling and Precise Dispatching
- Ergonomic Productivity Enhancement
- Equipment Productivity Optimization
- Manufacturing Process and Equipment Control
- Quality Monitoring and Control

Digital Transformation
- Augmented/ Mixed Reality
- AI Quality Control
- Digital Fab
- Remote Work System

Cross-fab Remote Collaboration

Intelligent Precision Manufacturing

Inter-fab Technology Transfer

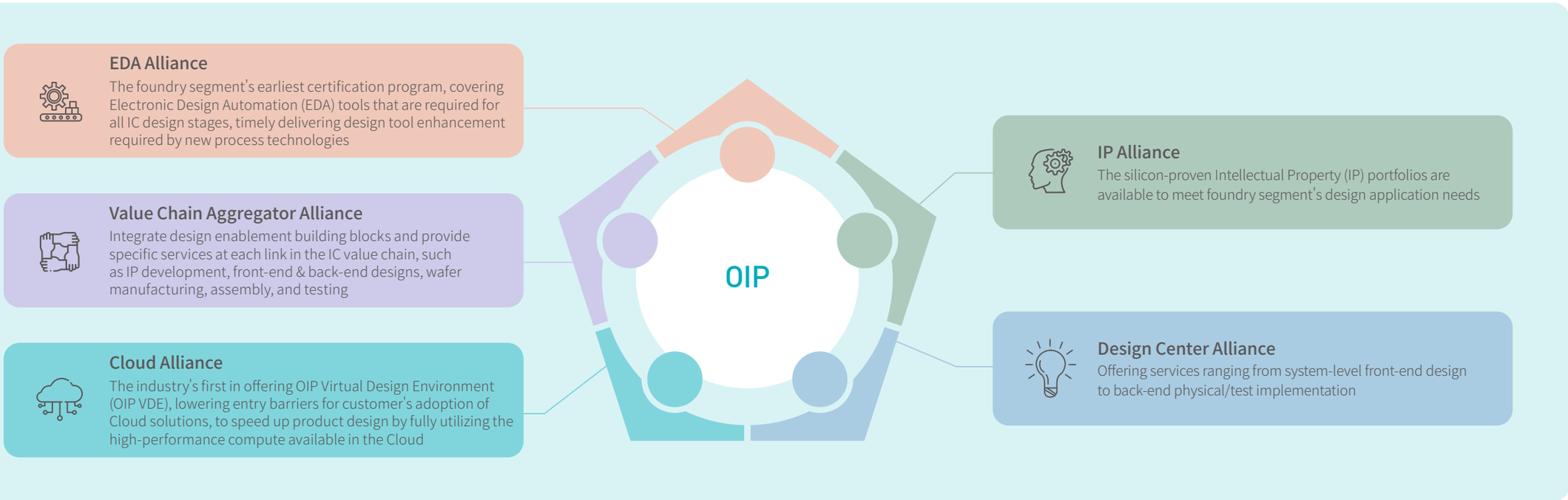
Open Innovation Platform®

TSMC's Open Innovation Platform® is a comprehensive design technology infrastructure that continuously drives innovation. It encompasses all critical IC implementation areas to effectively reduce design barriers and improve customers' first-time silicon success. Throughout the collaboration with OIP partners, spanning among five alliances of Electronic Design Automation (EDA), Intellectual Property (IP), Cloud, Design Center Alliance (DCA) and Value Chain Aggregator (VCA), TSMC actively synergizes and realizes innovative thinking, under the common goal of shortening design cycle time, time-to-volume, time-to-market, and ultimately time-to-revenue.

As OIP moves into its 13th anniversary, TSMC has been facilitating the collaboration & communication annually with OIP alliance partners on the latest process requirements, to infuse the most advanced semiconductor technology know-hows into their EDA, IP, Cloud products, and design services. Thus, TSMC continues to expand its ecosystem solutions to be timely available to customers so they can enhance Power, Performance and Area (PPA) in their products. This helps achieve co-optimization among TSMC process technologies, OIP enablement solutions, and customer product designs. By 2020, TSMC had provided customers with more than 12,000 different technology files and 450 Process Design Kits (PDKs) via TSMC-Online™ from 0.5um to 3nm, as well as a portfolio of more than 35,000 IP titles from 0.35um to 3nm. Those deliverables support customers for quick & reliable design and delivery of innovative products to fuel the incessant growth of global technology development.

In August 2020, TSMC held its online Technology Symposium and OIP Ecosystem Forum for the first time to maintain an important and close connection with worldwide customers and ecosystem partners during the COVID-19 pandemic.

TSMC's Five OIP Alliances



During the annual events, a complete set of design solutions were unveiled jointly with OIP alliance partners, as a result of tight partnership, to address the market demands for application-specific platforms of Mobile, High Performance Computing (HPC), Automotive, and IoT in the aspects as shown in the graph on the right.

TSMC was recognized by IEEE, the world's largest professional association dedicated to advancing technology, with the 2021 Corporate Innovation Award in December 2020 to highlight its leadership in foundry technologies along with its Open Innovation Platform®, which have enabled many revolutionary products in 5G mobile and energy-efficient, high-performance computing that have brought fundamental changes to the way we live and work.

"The IEEE extends its congratulations to TSMC for receiving the 2021 Corporate Innovation Award. TSMC's achievements in both developing 7nm technology, and enabling the innovations of IC designers everywhere, have placed it among a select group of organizations that have made lasting contributions to the field of engineering, and to the world."

—Dr. Toshio Fukuda, IEEE President and CEO

For the recognition of the contributions & outcomes that were delivered by OIP alliance partners from the collaborative activities, TSMC announced the 2020 OIP Partner of the Year Awards for Excellence in Accelerating Silicon Innovation.

Comprehensive Solutions in Advanced, Specialty and Wafer Level System Integration Technologies

Advanced Technology

3nm (N3)	▪ Design solutions are ready for Power Performance Area (PPA) exploration for smartphone and HPC applications
5nm (N5)	▪ Design solutions and ecosystem are ready and have been applied to real customer production chips ▪ Comprehensive automotive design solutions & ecosystem are under development
6nm (N6)	▪ Design solutions and ecosystem are ready and have been applied to real customer production chips
7nm (N7)	▪ Design solutions and ecosystem are ready and have been applied to real customer production chips ▪ Comprehensive automotive design solutions & ecosystem developed
N12e™	▪ Supports AI-enabled IoT products ▪ Contains design solutions for further speed/power enhancements
16nm	▪ Design solutions and ecosystem are ready and have been applied to real customer production chips ▪ Comprehensive automotive design solutions & ecosystem developed

Specialty Technology

- Integrated Specialty Technology Platform is established to provide optimal system-level solutions.
- The Platform covers NVM (Non-Volatile Memory), HV (High Voltage), Sensor, Bipolar-CMOS-DMOS (BCD), Ultra-Low Power/Ultra-Low Leakage (ULP/ULL), Analog, Radio Frequency (RF), and Logic technologies

Wafer Level System Integration Technology

- TSMC's 3DFabric™ is available to provide a family of advanced packaging solutions for Mobile and HPC design applications
- TSMC's 3DFarbric™ provides solutions that comprise Front-End (FE) 3D technology for chip stacking using SoIC™ (System on Integrated Chips), and Back-End (BE) technology for advanced packaging using InFO (Integrated FanOut) and CoWoS® (Chip on Wafer on Substrate)
- Design reference flows are available to support customer's 3DIC designs in chip, packaging, and system integration implementation & verification to enable better system performance

University Programs

Talent cultivation is among the five primary sustainable development goals of TSMC. Through collaboration with universities, TSMC is dedicated to enhancing domestic talent quality and industry competitiveness through STEM education. In addition to offering consistent resources, TSMC initiates university programs under three main themes: research collaboration, talent cultivation, and career exploration for students. In 2020, TSMC founded the TSMC Scholarship for Ph.D. Students and expanded the scope of semiconductor and IC layout design courses in the curriculum. The Company also hosted events like the TSMC X Microsoft Careerhack to continuously invigorate the innovative momentum in the industry.

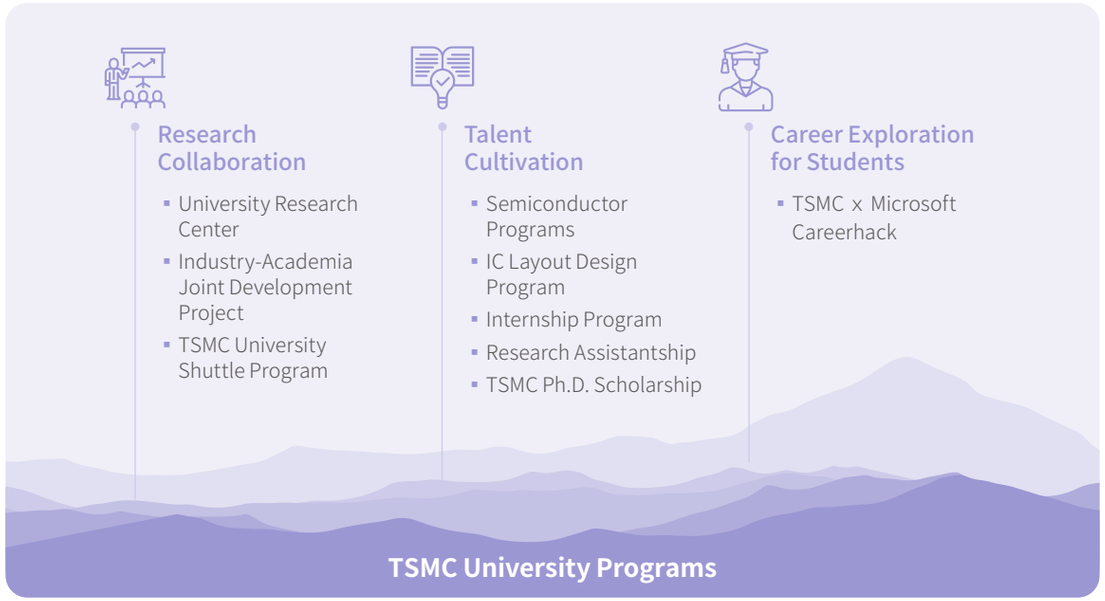
University Research Center

TSMC has established research centers in collaboration with top-ranked universities in Taiwan and dedicated research funds to encourage university professors to conduct groundbreaking semiconductor research projects. As the research centers strive to develop leading-edge technologies in semiconductor devices, material science, manufacturing process, and IC design, they are also training talents in semiconductor research. In 2020, more than 215 professors and 2,800 outstanding students in electronic engineering, physics, material science, chemistry, chemical engineering, and mechanical engineering joined TSMC's university research centers.

Industry-Academia Joint Development Project

TSMC works with universities in Taiwan and overseas to promote joint development projects. A variety of innovative research topics cover technologies in transistors, conductors, materials, simulation, and design technology. In 2020, TSMC collaborated with 89 professors in 25 universities on 86 industry-academia joint development projects. The annual research funds exceed NT$338 million, and over 157 U.S. patent applications were filed.

86 Number of Industry-Academia Joint Development Projects in 2020



Note: Learn more about the Internship Program in Talent Attraction and Retention- Talent Recruitment in this report.

University Research Center & Industry-Academia Joint Development Project

Collaboration Project	University	Beneficiary/Collaboration Details	Dedicated Resources
University Research Center	▪ National Yang Ming Chiao Tung University ▪ National Taiwan University ▪ National Cheng Kung University ▪ National Tsing Hua University	Beneficiary/Students and professors Offer research assistantship to encourage outstanding students to focus on the study of semiconductor devices, materials, manufacturing processes, and IC design without financial burdens	NT$17.88 million Nearly NT$17.88 million awarded in 2020 to 186 students[Note]
Industry-Academia Joint Development Project	▪ 10 universities in Taiwan and 15 universities overseas	Beneficiary/Professors Offer research funds to encourage university professors to propose new semiconductor research programs and cultivate semiconductor talents	NT$388 million A total of NT$338 million in research funds dedicated to 86 joint development projects in 2020

Note: The maximum grant amount given to an undergraduate department is 100 thousand, 120 thousand to a graduate program, and 360 thousand to a Ph.D. program. Grants were given to 86 undergraduate students, 55 graduate students, and 45 Ph.D. students in 2020.

TSMC Ph.D. Scholarship NEW

To facilitate the quality and R&D capabilities of key talents in Taiwan's semiconductor industry, TSMC launched a new Ph.D. scholarship in 2020, offering Ph.D. students NT$500,000 in grants per year to a maximum of five years, NT$2.5 million in total. The scholarship program also invites senior TSMC managers to be mentors in collaboration with university professors. By offering industry-academia research resources, outstanding students are encouraged to pursue Ph.D. degrees in studies pertinent to the semiconductor industry. A total of 22 students received the scholarship in 2020.

"I am honored to have received the recognition of TSMC's Ph.D. Scholarship and benefited from meeting the experienced mentors. Every lesson learned from the mentor gives me an in-depth understanding of the industry. I really appreciate TSMC for the resources and opportunity."

—Sheng-Tsung Lai, Ph.D. Student, Department of Electrical Engineering, Yuan Ze University

"Receiving TSMC's Ph.D. Scholarship is a huge encouragement for me. It's more than just a financial relief to me. The mentoring program enables me to more vividly envision my future research direction and life goals."

—Han-Fang Hsueh, Ph.D. Student, Division of Electronic Materials, Department of Materials Science and Engineering, National Taiwan University

Advanced IC Design Program

The complexity of IC design rises with the rapid advancement of design applications in 5G, AI, and high-performance computing. In keeping up with Moore's Law that drives the development of 5nm and more advanced technologies, it is becoming increasingly challenging for wafer manufacturing technologies to seamlessly cater to customer's IC designs. To ensure the competitiveness in power, performance, and area (PPA) of end products, TSMC is leading the industry in the cultivation of top IC design and layout talents well-versed in design & technology co-optimization (DTCO).

"TSMC's Advanced IC Design Program is very helpful in eliminating the industry-academia gap. Especially with TSMC instructors offering first-hand industrial knowledge, students get a more concrete sense of the industry's demand and the most up-to-date advanced process technologies. The program also helps students better identify their future goals and career plans."

—David Hung-I Su, Adjunct Professor at the Department of Engineering and System Science, National Tsing Hua University

58% Before the course, 58% of the students did not know that TSMC offers jobs in IC design

87% After the course, 87% of the students understand the key role TSMC plays in the IC design industry and look forward to joining TSMC in IC design jobs

	TSMC's Involvement	Course Detail	Frequency/Beneficiaries	Partnering University
TSMC Advanced IC Design Program (Pre-courses) NEW	University instructors ▪ Theories and teachings TSMC instructors ▪ Conduct circuit design case studies ▪ Demonstrate IC design flow in advanced technologies NEW ▪ Introduce key IC manufacturing process, layout techniques and IP resources ▪ Offer onsite tutorials and Q&A ▪ Offer summer internship opportunities	▪ Introduction to IC design and 3D IC in advanced technologies NEW ▪ Standard cell design in advanced technologies NEW ▪ IC layout ▪ IC layout in advanced nodes and apply AI in assisting IC layout NEW	**6 hours** Six hours per school **800 students** The complete program is to be launched in 2021. An estimate of **800** students will join the program. **150 students** A total of **150** students in 2020	▪ National Tsing Hua University NEW ▪ National Yang Ming Chiao Tung University NEW ▪ National Taiwan University of Science and Technology NEW More universities are next in line to join the program.
TSMC-NTUT IC Layout and Design Courses			**18 lessons** **18** lessons/semester **150 students** A total of **150** students since 2016	▪ National Taipei University of Technology

In 2020, the pre-courses of TSMC Advanced IC Design Program was first launched in National Tsing Hua University as an extended program based on the TSMC-NTUT IC Layout and Design Course that has been running for six years. A team of TSMC professionals carefully design course materials with a goal to expand the original IC layout courses into a comprehensive IC design program. In the courses, students learn about how TSMC maintains its technology leadership while shorting customers' time-to-market with DTCO design solutions, including electronic design automation (EDA) tool certification and design flow enablement for each new process technology. In December 2020, the pre-courses was launched at National Tsing Hua University, National Yang Ming Chiao Tung University, and National Taiwan University of Science of Technology.

The official launch of the TSMC Advanced IC Design Program will take place in the first semester of 2021. TSMC has also planned differentiated compensation packages as an incentive for students who finish the program to join the industry upon graduation. TSMC endeavors to continuously incubate semiconductor talents on campus and contribute to the growth of a domestic talent pool for semiconductor and IC design.

"The six-hour pre-course of TSMC's Advanced IC Design Program is invigorating. It not only deepens my understanding of TSMC but also gives me a clear view of practical IC design flow in advanced technologies. It has intrigued me to further join the semiconductor industry and thrive."

—Hung-Teng Wu, participant of the pre-course of TSMC Advanced IC Design Program and student of the Department of Power Mechanical Engineering, National Tsing Hua University

University Shuttle Program

Committed to the cultivation of semiconductor talents, TSMC helped professors and students of 16 universities around the world in turning IC design into actual chips and verifying their designs in application through the TSMC University Shuttle Program in 2020. The free-of-charge support also gives students a chance to access TSMC's industry-leading manufacturing process.

While over 70% of the schools involved in TSMC University Shuttle Program switched to teaching remotely in the wake of the COVID-19 pandemic in 2020, the program has not been jeopardized by the pandemic and distance. The number of publications made through the TSMC Shuttle Program of the year reached 93 in the year. In addition, the program has proven that student research is more than just innovative ideas but highly feasible designs that can become high-yield chips with the help of TSMC. Moreover, ten papers of the total publications were elected into the International Solid-State Circuits Conference (ISSCC), a prestigious conference known as the "Olympics of IC design."

In addition to 5G, wireless communications, memory application, Artificial Intelligence, wearable devices, security applications, and biotechnology, the research fields for the program in 2020 also covered global sustainability trends like low-energy-consumption technologies. Researches on energy efficiency, including UCLA's radio frequency research, Stanford University's biomedical research, UC Berkeley's wireless communications research, University of Michigan's pulse-injection crystal oscillator design, National Tsing Hua University's research on memory, and many applied research of National University of Singapore, are a strong indication that contemporary research is no longer focused on technological feasibility only. Power-saving features and durability which are the key factors in sustainable commercialization were also covered by the research.

"We have been working with the TSMC University Shuttle Program for the past years in the rapidly changing, wide range of memory applications. In addition to having cultivated numerous students of excellence dedicated to memory research, we regularly share our research findings at globally renowned conferences and journals which are met with acclamation across the industry, academia, and research institutions."

—Dr. Marvin M.F. Chang, Distinguished Professor at the Department of Electrical Engineering, National Tsing Hua University

"Thanks to the TSMC University Shuttle Program, the innovations we've worked tirelessly on were finally realized. Also, the early exposure to TSMC's industry-leading technologies gave me a competitive edge over my peers during job hunting."

—Dr. Win-San Khwa, Department of Electrical Engineering, National Tsing Hua University, a former participant of the TSMC University Shuttle Program (Now a Corporate Research engineer at TSMC)

2020 University Program Manufacturing Technology and Field of Research

Manufacturing Technologies Provided to Students

- Non-volatile memory (NVM)
- Analog signal circuits
- Digital signal circuits
- Mixed signal circuits
- RF circuit design
- Ultra-low power (ULP)

Research Applications in Recent Years

- 5G and wireless communications
- Memory applications
- Artificial Intelligence
- Wearable devices
- Security applications
- Biotechnology
- Automotive and drone related radar applications
- Data center internet backbone

Key Academic Collaborators and Research Direction in 2020

University	Professor	Research Project Title	Innovative Results	Application
National Taiwan University	▪ Shen-Iuan Liu	▪ Phase-locked Loop Based on Oscillator and Filter Integration	▪ Improve the sensitivity of voltage and temperature; fast phase lock with different input signal	●
National Taiwan University	▪ Tai-Cheng Lee	▪ Phase-locked Loop Based on Voltage Controlled Oscillator Using Sub-sampling Technique	▪ Sub-sampling techniques applied to a voltage-controlled oscillator to effectively reduce noise under 5G high-frequency environment	●
National Tsing Hua University	▪ Chrong-Jung Lin ▪ Ya-Chin King	▪ Stackable 3D Resistive Random Access Memory (RRAM)	▪ Identical chip size to allow for more usable memories under three- dimensional structures	● ●
National Tsing Hua University	▪ Meng-Fan Chang	▪ Color image recognition and high energy-efficient computation using Resistive Random-Access Memory (RRAM) and Static Random Access Memory (SRAM)	▪ High-speed parallel computational memory featuring both storage and computation functionalities to drastically reduce the latency and space overheads of data movement in traditional edge processors, thereby speed up computation and reduce energy consumption	● ● ●
National University of Singapore	▪ Massimo Alioto	▪ Error-correcting and Physically Unclonable Function (PUF) Based Key Generation Architecture	▪ Equipped with error correcting function integrated with machine learning to significantly reduce voltage and temperature sweeps compared with traditional unclonable key generation structure	●
National Yang Ming Chiao Tung University	▪ Shyh-Jye Jou	▪ A Communication Millimeter-wave Baseband System with Self-healing and Testing functions	▪ Using Smart Sensing Technique and calibration method to reduce the complexity of analog circuit design and increase communication throughput	● ●
National Yang Ming Chiao Tung University	▪ Wei-Zen Chen	▪ 112-Gb/s PAM4 Cable Transmitter and Receiver	▪ A novel optimized algorithm for data/clock recovery on circuit, integrated with ultra-low-noise frequency synthesis technique to enhance modulation capacity	● ●
National Yang Ming Chiao Tung University	▪ Yen-Cheng Kuan	▪ W-band Multi-user Interference-tolerant Radar System	▪ High-precision frequency hopping radar system supporting simultaneous operations of multiple users without interfering with one another	● ●
University College Dublin	▪ Robert Bogdan	▪ Low-power Phase-locked loop Based on Charge-Sharing Locking Quadrature	▪ Suppress oscillator phase noise and achieve ultra-low jitter through enhancing phase noise endurance and injecting energy into oscillator	●
University of Michigan	▪ David Blaauw ▪ Dennis Sylvester	▪ Ultra-low-power Crystal Oscillator with High-energy Pulse Injection	▪ Injected with frequency-divided, high-energy, low-frequency pulse to significantly reduce power consumption and disturbing of the crystal oscillator	●

● 5G ● High Speed Ethernet Technologies ● Wireless Communication ● Automotive ● Drones ● AI ● Wearable Devices ● Memory Applications ● Security Applications

Note: Cooperative partners are sequenced in alphabetical order.

Case Study

Virtual Design Environment (VDE) in the Cloud Created a New Model for Industry-academia Collaboration, Contributing to the Tape-out Success of TSMC's First Academia-Developed 16nm FinFET Chip through University Shuttle Program

TSMC continues to expand R&D activities to secure its leadership in semiconductor technologies. As the development of TSMC's advanced manufacturing technology is moving forward at full speed while also maintaining the protection of TSMC proprietary information, TSMC launches the University Shuttle Program to share its process technologies with university professors and students for research. The program actively bridges the gap between academia and the industry.

"Through VDE, the first N16 FinFET University Shuttle Program chip tapeout was achieved. Stanford University and TSMC have created an innovative model for industry-academia collaboration that amplifies top research results by integrating advanced industrial process technology. It inspires more innovation to become a reality in the semiconductor industry. "

—Dr. Philip Wong, Chief Scientist at TSMC

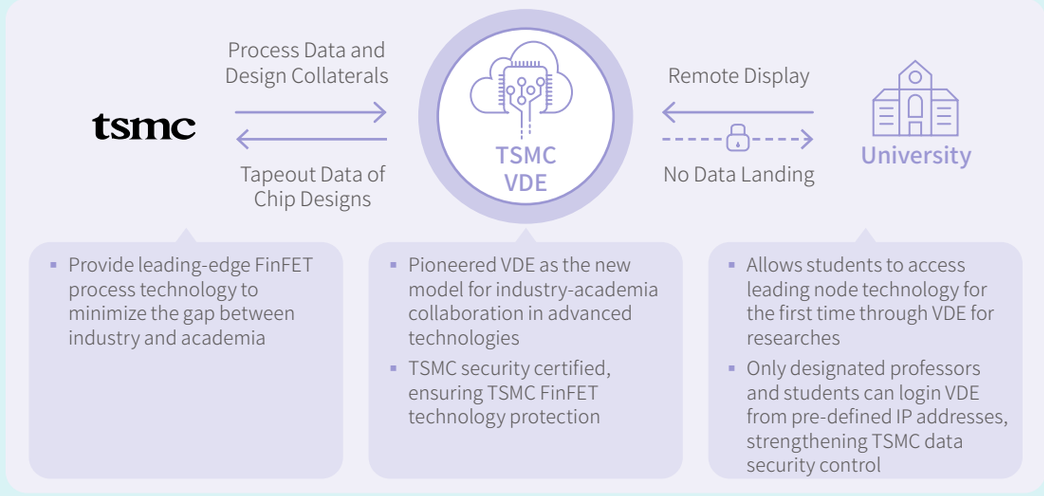
"TSMC University Shuttle Program in conjunction with the Virtual Design Environment in the cloud is simply an unprecedented combination. Students get to realize their innovative ideas using industry-leading advanced process technology. It is an incentive to attract more talents to join the semiconductor industry. "

—Dr. Mau-Chung Frank Chang, Distinguished Professor at UCLA

In 2020, TSMC expanded the architecture of Virtual Design Environment (VDE) in the cloud that was originally intended only for customers. After eliminating the concerns in information security, universities now can access TSMC advanced technology process database via VDE remotely to support research and teaching on IC design. This innovative cloud-based solution has greatly helped universities to take a stride directly into N16 FinFET technology for the first time, by two to three generations ahead of previously applicable process technologies in 40nm and 28nm.

To amplify the impact of TSMC's University Shuttle Program, TSMC offered N16 FinFET technology to universities in 2020, starting from the long-term industry-academia collaboration with Stanford University in the United States. A research team led by Dr. Mark Horowitz of Stanford's Electrical Engineering Department was the first to adopt the Virtual Design Environment (VDE) for the research on AI accelerator chips for deep neural network (DNN) in N16 FinFET technology. In December of the same year, the research team transmitted the IC layout design through VDE to TSMC and completed tapeout. Through TSMC's University Shuttle Program, the IC design was realized in actual silicon. This is the first N16 FinFET chip created by academia through TSMC University Shuttle Program and it advanced AI research in a big way.

Meanwhile, another long-time partner, the UCLA research team has also started research on RF circuits based on N16 FinFET process technology via TSMC VDE that will be under the guidance of distinguished professor Dr. Mau-Chung Frank Chang.



TSMC University Shuttle Program Facilitates Foresight IC Design