A Sponsored Supplement to *Science*

90 years of scientific advances at the Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences

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Cover: The teapot and cups—forming the "90" that highlights SIMIT's 90th anniversary—represent research and resources flowing into three units created by SIMIT: SIMIC Holdings for industrialization, the Shanghai Industrial μTechnology Research Institute (SITRI) for technology transfer, and the Center for Excellence in Superconducting Electronics (CENSE) for superconducting quantum devices and circuits research.

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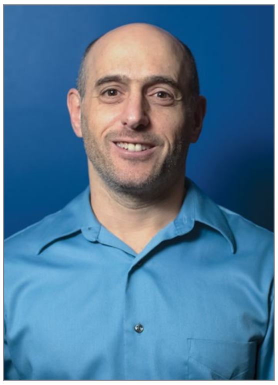
Xiaoying Chu
Director, Global Collaboration and Business Development, Asia
xchu@aaas.org
+86-131-6136-3212

Danny Zhao
Regional Sales Manager, Asia
dzhao@aaas.org
+86-131-4114-0012

8 June 2018

Introductions

Chapters



90 years young

2018 marks the 90th anniversary of SIMIT's founding, making it modern China's oldest national institute.

From its humble beginnings in 1928 as the Institute of Engineering, Academia Sinica, the Shanghai Institute of Microsystem and Information Technology (SIMIT)—part of the Chinese Academy of Sciences (CAS) since 1950—has grown to become one of China's premier information technology research institutes.

2018 marks the 90th anniversary of SIMIT's founding, making it modern China's oldest national institute. To help celebrate its achievements over these past nine decades, we present this supplement to *Science*, in which the reader will find a wealth of information about SIMIT's past and present. Chapter one provides a brief background, including SIMIT's history and scientific achievements. The second chapter gives a detailed look at current research at the institute, outlining its primary areas of endeavor, namely intelligent sensing microsystems, superconducting quantum devices, advanced silicon-based materials, broadband wireless communication technologies, micro- and nanotechnologies for sensors and transducers, phase-change random access memory and its applications, terahertz solid-state technologies, and brain-inspired chips and bionic vision. Together, these research areas advance the field of information technology in China while also satisfying its domestic economic and research priorities, and addressing national security priorities.

Chapter 3 walks the reader through the five major research platforms established by SIMIT. These range from a production line for microelectromechanical systems (MEMS) and other "More-than-Moore" (MtM) technologies, to a platform for the microstructural characterization of functional materials for informatics applications. Also described is the Superconducting ELectronics Facility (SELF), one of the world's most advanced R&D platforms for the fabrication and testing of superconducting devices and circuits. It is an open, shared platform, available to domestic and international researchers as a service, or through collaborative projects.

SIMIT's unique "Three-in-One" Collaborative Innovation System is described and explained in chapter 4. This system brings together research know-how from SIMIT, technology transfer expertise from the Shanghai Industrial µTechnology Research Institute (SITRI), and industry knowledge from SIMIC Holdings, SIMIT's capitalization and investment arm. This model was born out of CAS's guiding principle of driving innovation that supports national needs.

The final two chapters, 5 and 6, highlight SIMIT's international outreach and collaboration, and introduce some of its globally recognized staff. SIMIT is proud of its collaborative approach to basic research, having established cooperative agreements with research centers throughout the world, including Germany and Finland. Its staff numbers over 600, including 80 foreign researchers as well as many winners of prestigious domestic awards.

At 90, SIMIT is still a young and growing institute. As it approaches its 100th anniversary, it is not resting on its laurels. It continues to expand and attract exceptional talent from within China and around the world. It welcomes top applicants (see chapter 7) who wish to be involved in cutting-edge electronic science and technology research, and information and communication technology development.

We wish the institute and its staff congratulations on reaching this milestone and look forward to seeing it move from strength to strength over the next decade and beyond.

Sean Sanders, Ph.D.
Science/AAAS Custom Publishing Office

PHOTO: ALEX LEE

From the Director

Our primary focus at SIMIT is to better apply scientific and technological breakthroughs to the harmonious development of society and the sustainable growth of the Chinese economy.

On the 90th anniversary of the Shanghai Institute of Microsystem and Information Technology (SIMIT) at the Chinese Academy of Sciences (CAS), we are proud to sponsor this supplement produced by the *Science*/AAAS Custom Publishing Office and present it to international readers and researchers. This is a new and unique opportunity for SIMIT to provide a broad description of its research, scientific platforms, collaborative innovation, international cooperation, talent, achievements, ongoing projects, and future visions to the global research community.

SIMIT is a respected national institute with a long and rich scientific research history, being one of the first national research institutes in China. Since the establishment of the Institute of Engineering, Academia Sinica, in 1928, multiple generations of scientists have made significant advances in answering critical scientific questions. Their dedication, passion, and achievements laid a solid foundation upon which modern-day SIMIT has been built.

Over the past 90 years, despite numerous changes in research focus, SIMIT has consistently followed the unchanging principle that it must continually adjust and adapt to meet the demands of China's strategic and economic growth. In the last 20 years in particular, research and development at the institute has focused on basic science and technology, as well as strategic advanced technologies related to emerging industry development. By aligning the objectives and interests of the institute with the needs of society, SIMIT aims to catalyze innovation for the advancement of the country.

Today, science and technology are advancing at an unprecedented pace. Our primary focus at SIMIT is to better apply scientific and technological breakthroughs to the harmonious development of society and the sustainable growth of the Chinese economy. As we enter a new era of Chinese-styled socialism, the nation is moving toward a historic moment of great rejuvenation. The national goal of strengthening the country's system of innovation and enhancing the power of China's scientific research is motivating SIMIT to take advantage of this unique opportunity to play a leading role in the nation's technological development.

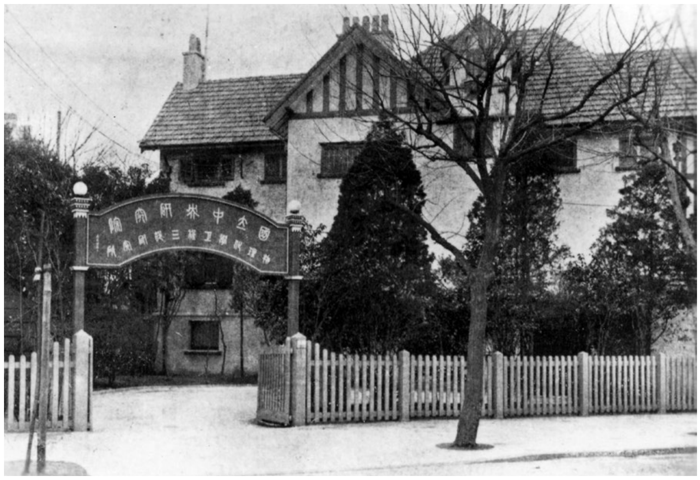
Looking to the future, SIMIT will retain its focus on remaining at the forefront of science, national priorities, and economic progress, while improving its capacity for innovation and enhancing its proficiency in information and communication technology. At the same time, we will also attach importance to solving key scientific and technical problems in the areas of intelligent sensing microsystems, superconducting quantum devices and circuits, and advanced silicon-based materials. SIMIT will continue to innovate, striving to maintain its position as an irreplaceable national scientific research institution.

I wish to express my appreciation to my colleagues, whose efforts and dedication made this supplement possible. I sincerely hope it will encourage future collaborations between SIMIT and scientists in many diverse fields from around the world.

Professor WANG Xi, Ph.D.
Director of SIMIT, CAS

Overview of SIMIT

The Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences (SIMIT, CAS)—formerly known as the Institute of Engineering, Academia Sinica—was founded in 1928 and is China's oldest engineering research institution. In 1950, it became part of the newly established Chinese Academy of Sciences, and was renamed the Engineering Laboratory, CAS. Its name changed multiple times over the next five decades, finally becoming SIMIT in May 2001. The institute is proud of its long legacy as the oldest national institute in modern China.



SIMIT's first location in 1928: 899 Xiafei Road (now 1337 Middle Huaihai Road)

Historical achievements

In its 90 years of development, SIMIT has been awarded 48 national science and technology awards, with some projects winning prestigious honors, including a Special National Science and Technology Progress Award for "Fabrication Technology for A-Separation Membrane," and two First Class National Science and Technology Progress Awards for "High-Speed and Ultrahigh-Speed Bipolar Digital Integrated Circuits" and "Research and Industrialization of Silicon-On-Insulator (SOI) Materials."

In the 1950s, SIMIT was the first institute to successfully develop spheroidal graphite cast iron domestically and the first to establish an ultrapure metal and III–V compound semiconductor materials research base. In the 1970s, SIMIT developed microelectronics and integrated circuit (IC) manufacturing technology for China. In collaboration with industry partners, SIMIT developed industrial PN junction–based isolation ICs, emitter-coupled logic (ECL) high-speed circuits, and 8-bit and 16-bit microprocessors, all firsts for the country. In the 1980s, SIMIT led the research on microelectromechanical systems (MEMS) and silicon-on-insulator (SOI) development in China.

From 1998, SIMIT broadened its research scope from materials science to information and communication. The institute created a strategic plan summarized as "systems drive devices, devices drive materials," emphasizing electronics science and technology; information and communication engineering including wireless information systems and networks, microsystem technologies, and functional materials and devices for information technology; and micro-type and new energy sources. SIMIT successfully launched the Chuangxin No. 01 and 02 satellites and the Shenzhou VII companion satellite. It quickly became an important base for R&D of microsatellites in China. SIMIT implemented the Shanghai World Expo Intrusion Prevention Sensor Network, the Pudong Airport Intrusion Prevention System, the Taihu Lake Water Quality Monitoring Sensor Network, the Security System for the central line South-to-North Water Diversion Project, and other Internet of Things (IoT) application pilot projects. The institute led the development of IoT core technology and promoted it as a national strategic emerging industry. Additionally, SIMIT developed broadband wireless communication systems with independent intellectual property rights. These systems were deployed for the Wenchuan and Yushu earthquake relief efforts, the Shanghai World Expo, and other major events in China. The broadband wireless communication system played an invaluable role in the earthquake relief work, providing social stability and enhancing public safety and security. SIMIT established Shanghai Simgui Technology Co., Ltd., the first and only world-class advanced SOI materials manufacturer in China. Simgui's products addressed the gaps in domestic SOI material needs and have been used in key state projects.

During the 12th Five-Year Plan period (2011–2015), as a leading technical institute within CAS, SIMIT made breakthroughs in multifunctional compound sensors and related key technologies. The institute worked on providing special broadband wireless sensor network system solutions and related large-scale devices, and on transitioning the country's wireless communication system from narrowband to broadband. SIMIT successfully developed the first domestic large-scale, high-reliability, dedicated application-specific integrated circuit (ASIC) chip based on the 0.13-μm SOI process. The chip was used in the Beidou navigational satellite and other key national projects. This helped to lay a solid foundation for the self-sustained design and manufacture of core spacecraft components in China. With the support of the superconducting nanowire single-photon detector (SNSPD) from SIMIT, Academician Pan Jianwei of the University of Science and Technology of China has globally pioneered the implementation of a hacker-proof, 200-km measurement-device-independent quantum encryption key distribution system. This project was selected as one of the top 10 scientific and technological achievements of 2014 by academicians from CAS and the Chinese Academy of Engineering. Another development, an ultra-high-speed gravity acceleration sensor, was a critical component of certain pieces of strategic equipment in China. The ability to develop such a sensor lessens the effect of potential international embargoes. SIMIT also launched a MEMS technology industrialization platform known as the Shanghai Industrial μTechnology Research Institute (SITRI), now regarded by the Shanghai government as one of the "beams and pillars" of the globally influential Shanghai Technology Innovation Center.

SIMIT's Xingfo Building

Jiading Campus of SIMIT

Research strength

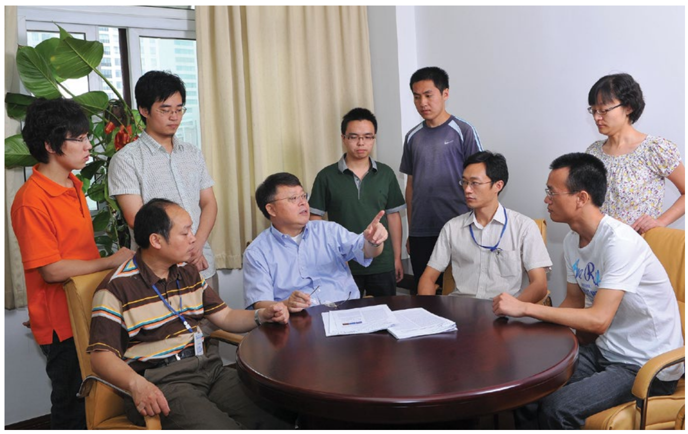
SIMIT includes three national-level key laboratories: the State Key Laboratory of Transducer Technology, the State Key Laboratory of Functional Materials for Informatics, and the National Key Laboratory of Microsystem Technology. Two CAS key laboratories are also part of the institute: the CAS Key Laboratory of Wireless Sensor Networks and Communications and the CAS Key Laboratory of Terahertz Solid-State Technology, as well as the Center for Excellence in Superconducting Electronics (CENSE). Currently, SIMIT has seven research departments: the Department of Micro/Nano Technologies for Sensors and Transducers, the Department of Functional Materials for Informatics, the Department of Terahertz Solid-State Technology, the Department of Wireless Sensor Networks, the Department of Broadband Wireless Technology, the Department of Superconductors, and the Department of Bionic Vision Systems. Six affiliated groups scattered around China, in Nanjing, Hangzhou, Jiaxing, Fuzhou, Chengdu, and Nantong, are also part of the institute. SIMIT also has several joint partnerships, including laboratories with the Juelich Research Center (Forschungszentrum Jülich GmbH) of the Helmholtz Association, the Collaborative Innovation Center for High-Reliability Components with the CAS Shanghai Engineering Center for Microsatellites, and the Joint Laboratory on Superconducting Quantum Devices and Quantum Information with the University of Science and Technology of China.

Talent

SIMIT plays a key role in cultivating talent and supporting nationwide science and technology development by attracting world-class faculty members. Currently, the institute employs 610 full-time staff members, of whom 87 are full professors. Nearly 700 students also work at SIMIT. Over the years, SIMIT has built a highly educated and ambitious team that has won several CAS funding awards, including four National Outstanding Young Scientist Fund awards, seven National Thousand Talents Plan awards, two National Thousand Young Talents Plan awards, and 22 Hundred Talents Plan awards. CAS academicians as well as international associates of the U.S. National Academy of Sciences, together with the rest of the SIMIT staff, are dedicated to nurturing exceptional talent in addition to producing world-class scientific research.

Innovation

Since SIMIT was established, it has displayed a pioneering spirit of innovation and entrepreneurship. It has developed state-of-the-art technologies across a broad range of fields, and has instituted the "Three-in-One" Collaborative Innovation System to promote technology transfer and industrialization of scientific and technological achievements. This system consists of SIMIT leading the principal technology R&D, SITRI as the technology transfer platform, and SIMIC Holdings as the industrialization partner, combining technology and finance.



JIANG Mianheng (fourth from left) mentoring students at SIMIT

Future vision

According to the new CAS operating principle of "an orientation toward the forefront of international science and technology, major national demands, and primary challenges of the national economy," SIMIT will fully utilize its advantages in electronic science, technology, information, and communication engineering to solve key scientific and technical problems through the design and application of intelligent sensing microsystems, superconducting quantum devices and circuits, and advanced silicon-based materials. SIMIT also aims to promote the application of major research achievements, in addition to becoming a "Four First-Class" institution and an irreplaceable national research treasure in the information and communication technology field.

Scientific research at SIMIT

To fulfill its mission of meeting national needs in China, SIMIT has been conducting strategic, innovative, and forward-looking research with the aim of promoting breakthroughs in key technologies and multidisciplinary innovation, providing systematic solutions, and contributing to the development of information technology, advanced materials, and micro-/nanotechnologies. Under the Chinese Academy of Sciences (CAS) innovation plan of "focusing on international cutting-edge science and technology, major national demands, and the main challenges of the national economy," SIMIT has established a research strategy consisting of three major breakthroughs and five top priorities that mirror its strengths in electronic science and technology (S&T), information systems, and communication engineering.

The three major breakthroughs are as follows:

Intelligent sensing microsystems (ISMs). SIMIT aims to fulfill national needs by enhancing wireless sensor networks, expanding the industrial Internet of Things (IoT), and creating an information database for national security and industry applications.

Superconducting quantum devices and circuits. SIMIT focuses on basic scientific research on quantum materials and devices, with the broad goal of developing proprietary advanced superconducting core electronic devices and integrated systems.

Advanced silicon-based materials and applications. SIMIT is devoted to the research and industrialization of advanced silicon-on-insulator (SOI) materials and 12-in. silicon wafers for China's semiconductor and microelectronics industries.

The five top priorities are as follows:

1. *Special broadband wireless communication technologies and equipment*. Research on key wireless communication technology that enables concurrent transmission using orbital angular momentum and signal energy is being prioritized, together with the development of broadband wireless communication technology dedicated to high-speed rail and smart power grids.

2. *Micro- and nanotechnologies for sensors and transducers*. Research on state-of-the-art microelectromechanical or nanoelectromechanical systems (MEMS/NEMS) technologies for physical, chemical, biochemical, implantable, and compound combination sensors, as well as hyperspectrum detection microsystems.

3. *Phase-change random-access memory (PCRAM) and applications*. Research on the electrical, thermal, and crystallographic principles of low-power, high-speed, reliable phase-change memory units to drive the engineering of PCRAM chips.

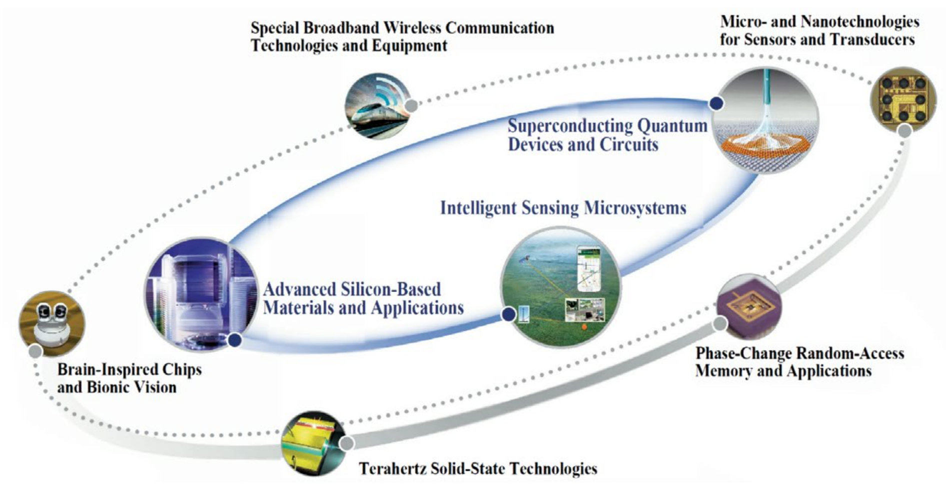
4. *Terahertz (THz) solid-state technologies*. Research on THz radiation sources, the detection principles of THz quantum cascade lasers, the interaction between THz waves and various materials, millimeter-wave monolithic integrated circuits (ICs), and millimeter-wavelength inspection and imaging equipment.

5. *Brain-inspired chips and bionic vision*. R&D of brain-inspired chips and bionic vision systems, including binocular image signal processing chips, sensors that replicate the five human senses, and robotic limbs.

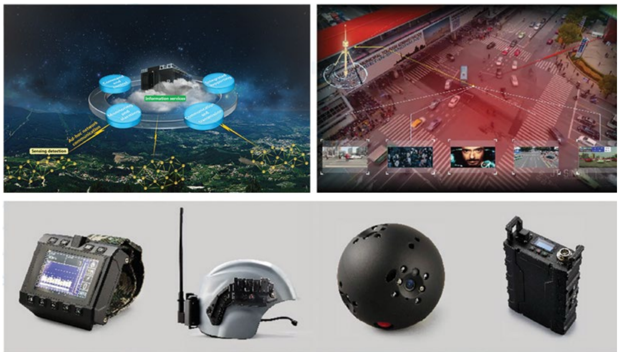
Intelligent sensing microsystems

The development of ISMs involves cross-disciplinary research encompassing traditional sensors as well as emerging IoT technology. Domestically, both wireless microsensor networks and intelligent terminal equipment have been developed in China for national security and industrial applications. More importantly, SIMIT holds core intellectual property assets related to hybrid-target cooperative detection, recognition algorithm architectures, equipment miniaturization, low power consumption, large-scale random networking, and heterogeneous system fusion. Dozens of ISM standards proposed by SIMIT have been accepted by standardization organizations in China and Europe.

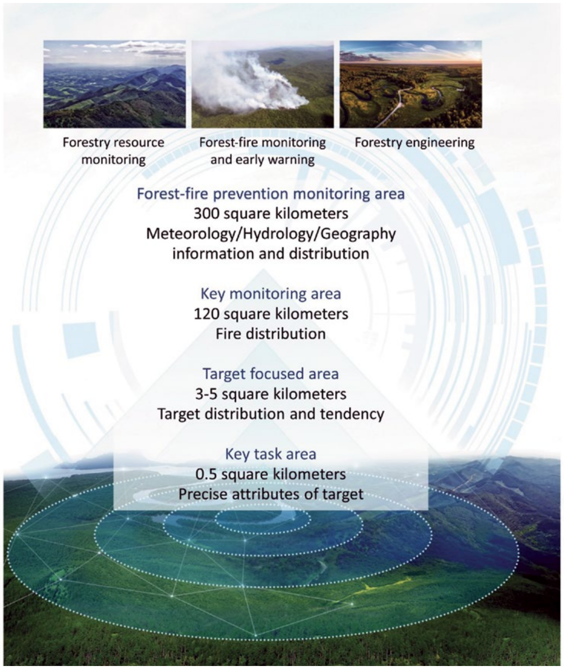
Based on a proposal by CAS in 1999, SIMIT established a research team for wireless sensor networks that became the first group to study both sensors and IoT in China. SIMIT has become the central department of the Shanghai IoT League, the core and leading institute for sensors and IoT R&D at CAS, and the central and technical lead unit in the field of sensing and reconnaissance equipment in China. Subsequently, SIMIT has also become the secretariat of the standardization working group for the Chinese sensor network and made numerous proposals for setting international standards. To further consolidate R&D teams and promote the innovation and development of sensors and IoT technology, SIMIT set up the Wireless Sensor Network Department in May 2015. The ISM team, working within this department, received a Shanghai S&T Progress Award (first prize) in 2008 as well as the S&T Progress Award for the Chinese People's Liberation Army in 2010. Yuan Xiaobing, the



Representation of research directions at SIMIT under the 13th Five-Year Plan (2016–2020). The three breakthroughs are shown in the center ring, surrounded by the five priorities.



Applications and examples of intelligent sensing microsystems (ISMs). Top row: Applications of ISMs including emergency communication systems. **Bottom row:** Devices containing ISMs, including a wrist-mounted terminal, a communications helmet, a reconnaissance ball, and a communication replay device.



The forestry Internet of Things

Forestry fireman using a personal intelligent sensing microsystem

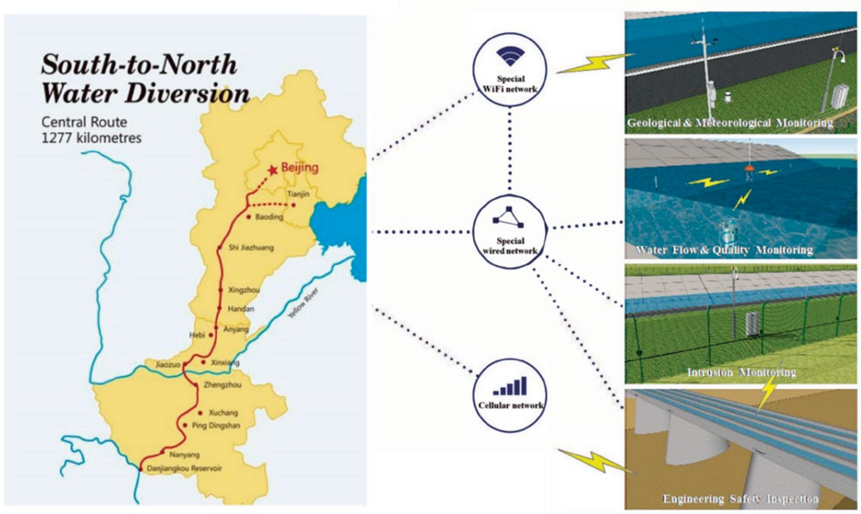
team leader and deputy director of SIMIT, won the Advanced Individual Award from the General Equipment Department and the Ministry of Industry and Information Technology in 2012 and was honored by the State Council of the People's Republic of China.

ISMs developed at SIMIT have attained worldwide prominence because of their technical advantages in two major areas. First, SIMIT constructed an innovative sensing network architecture, including sensing equipment, a sensing index system, and an application model. An ISM consists of integrated sensors and communication devices. Through systematic integration, functional integration, and complementary morphology, the success of various sensing applications has been demonstrated. The latest, third-generation sensing equipment architecture incorporates upgrades that provide significant improvements in the scale, functionality, and networking capabilities of sensing equipment.

Second, SIMIT used key advantages of ISMs, such as multimodal heterogeneity, multitasking ability, and stochastic dynamics, to create a special collaborative sensing network that addressed a number of technical challenges including task-oriented target recognition in complex environments, antienvironmental interference, network adaptation and self-reconfiguration, and multisource information fusion.

SIMIT found that accuracy in the detection of target distance using the latest ISMs could be increased by over 30%. Moreover, the accuracy of single-sensor target recognition could be increased to more than 95%, and the accuracy of multisensory fusion target recognition could be improved to more than 98%. Certain performance indexes exceeded those of similar equipment produced internationally. When SIMIT first researched randomly distributed networking and covert communication in special sensor networks, it made advances in dynamic cross-layer protocol optimization, double cluster topology control, and dynamic multiple access control (MAC), among other areas. A sensing network platform with a multidimensional reconnaissance system, multisource acquisition, and sensor information fusion has been constructed. It significantly improves ISM network self-expansion, self-reconfiguration, anti-jamming ability, and mobile survivability, and helps to simultaneously expand the capabilities of various reconnaissance sensors in the ISM from single sensors to network groups. Furthermore, SIMIT's research demonstrates that the use of broadband spread-spectrum communication technology, multipath rake receiver technology, fast frequency synchronization technology, and fast code chip synchronization technology can effectively improve the performance of anti-jamming, anti-capture, and information shielding systems in ISMs.

Recently, certain sensors employed in MEMS technology have been co-opted for ISMs. These sensors now feature integrated circuits, high-speed-algorithm hardware, complex-logic software, the MAC protocol, and an energy-efficient mixed-measurement routing algorithm. This enables their further miniaturization and concomitant reduced power consumption. Extensive experiments have shown that these new sensors can greatly improve reconnaissance equipment performance. Compared with the previous generation of equipment, both the weight and power consumption of the new MEMS-enhanced equipment can be reduced by 70%. Instruments such as the ISM tactical terminal have enabled the creation of an integrated information network that allows the seamless linkage of equipment, personnel, and information systems as well as interconnections between all communication terminals and from terminals to the central communications center.



Large-scale sensor network development for the security system constructed for the central line South-to-North Water Diversion Project

A personal communication system for individual forestry firemen as well as a forestry IoT were developed at SIMIT utilizing ISMs. The ISM links personnel and transportation and integrates "fire situation, self-situation, and environment" in an innovative forest-fire prevention command system. In a Chinese national fire drill, it was highly praised by the director of the State Forestry Administration. They agreed that a system with civil–military integration, advanced technology, and strong practicability was essential for forest-fire prevention. Additionally, a public security system based on ISM has been popularized and applied in Shanghai Pudong Airport, Hongqiao Airport, Shanghai Expo Park, the central line South-to-North Water Diversion Project, the Shanghai Public Security Bureau, and the Zhejiang Maritime Safety Administration, among others. These applications have resulted in significant economic and social benefits.

Since wireless communication plays an important role in ISMs, SIMIT set up the Key Laboratory of Wireless Sensor Networks and Communications, CAS, which is dedicated to major national strategic and application requirements. The laboratory is committed to fundamental research, application development, systems integration, and the development of testing and evaluation technologies for wireless sensor networks and broadband wireless mobile communication. It aims to establish industry-leading wireless sensing networks and mobile communication systems.

The main research directions of the Key Laboratory of Wireless Sensor Networks and Communications include: (1) intelligent networking technology using wireless sensor networks, (2) efficient wireless transmission technology, (3) integration solutions and information processing technology related to wireless sensor networks, and (4) technology for testing and evaluating wireless systems. In addition, a large-scale application demonstration system will be set up to promote the standardization of wireless sensor networks and next-generation broadband mobile communication.

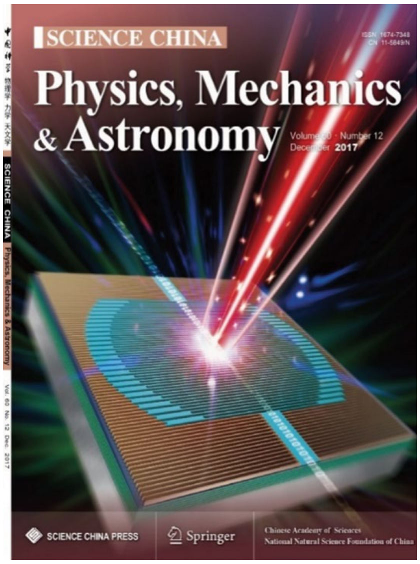
In the future, ISMs will focus on target detection technology with microaperture arrays, adaptive technology for sensing under complex conditions, deep intelligent front-end sensing technology, and ultra-large-scale dynamic intelligent networking technology. Furthermore, new wearable information terminals and next-generation wireless sensing systems will be developed in the future. The team will strive to meet the demands for national defense, national security, and public safety.

Superconducting quantum devices and circuits

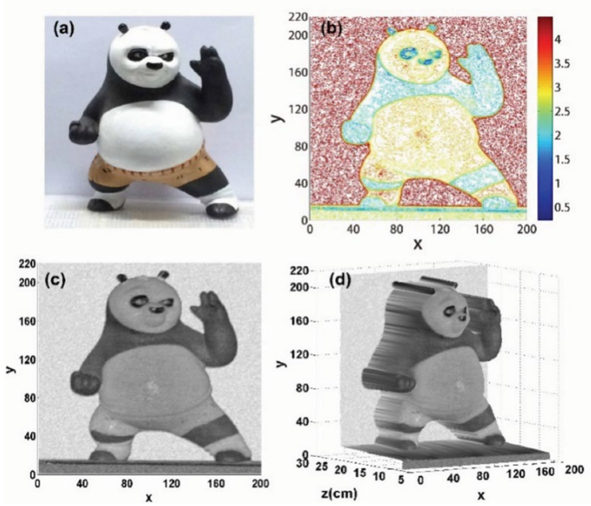
Superconducting electronics is an interdisciplinary research area involving superconducting physics, materials science, and electronic technologies. The scope of superconducting electronics includes superconducting passive devices, sensors, detectors, digital electronics, and quantum bit circuits. Superconducting devices and circuits have high performance and hence play indispensable roles in ultrasensitive detection, high-precision measurements, quantum information processing, quantum metrology, and many other important research areas.

SIMIT has historically formed the backbone of research on superconductivity in China. It has achieved many successes, including the development of China's first low-temperature superconducting wire and the creation of a high-temperature superconductor with the world's highest critical current density for melt texturing. In 2005, the major focus of superconductivity research at SIMIT changed from superconducting materials to superconducting electronics. After more than 10 years of effort, SIMIT deployed the development strategy for a superconducting electronics research facility and a world-class fabrication platform for superconducting quantum devices and circuits. Many breakthroughs, such as a superconducting nanowire single-photon detector (SNSPD) and superconducting quantum interference device (SQUID), have been realized and validated in a variety of applications.

In 2015, the CAS Center for Excellence in Superconducting Electronics (CENSE) was formally founded. CENSE focuses on applied fundamental research in superconducting electronics. Committed to meeting national strategic requirements and remaining at the forefront of the superconducting electronics field, it is dedicated to top-level research on quantum materials science, superconducting sensors/detectors and their applica-



Cover Image for *Science China: Physics, Mechanics & Astronomy* issue (December 2017), showing a schematic of a superconducting nanowire single-photon detector (SNSPD) (*1*).



Few-photon imaging based on time-of-flight laser ranging using an SNSPD (*2*).

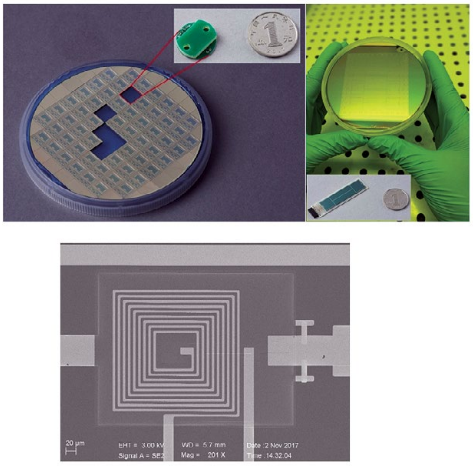
tions, superconducting ICs, and superconducting computers. By undertaking several major research programs, CENSE aims to build an interactive research environment for materials, devices, and applications, and to construct a multidisciplinary platform for both scientific achievement and talent development. Its goal is to build a world-class research center in superconducting electronics and to develop independent intellectual property related to superconducting chips, devices, and systems.

CENSE is working on some key detectors, among which are SNSPDs. CENSE focuses on the fabrication and function of SNSPDs based on ultrathin niobium nitride (NbN) films. Related studies include the growth of ultrathin superconducting films, detection mechanisms, design and fabrication of SNSPDs, and key parameters of SNSPDs. A correlation was found between the factors that determine both the absorption and intrinsic detection efficiency of SNSPDs. By optimizing the fabrication parameters, an NbN SNSPD was demonstrated using a Gifford–McMahon (GM) cryocooler, having a system detection efficiency (SDE) of over 90% at 1550 nm. By understanding the origin of dark counts, SIMIT developed on-chip and fiber-endface bandpass filter technologies to suppress the dark count rate (DCR) to less than 1 Hz while maintaining an SDE as high as 80%. The contribution of each part to the timing jitter (TJ) of the system was quantitatively analyzed, and a system with a TJ of 14 picoseconds (ps) was obtained. The wavelength range of the SNSPD was extended from the near-infrared to visible wavelengths. The typical SDE is approximately 80% for all wavelengths. Furthermore, CENSE proposed and fabricated novel SNSPDs such as microfiber-coupled SNSPDs and SNSPDs with a high polarization sensitivity.

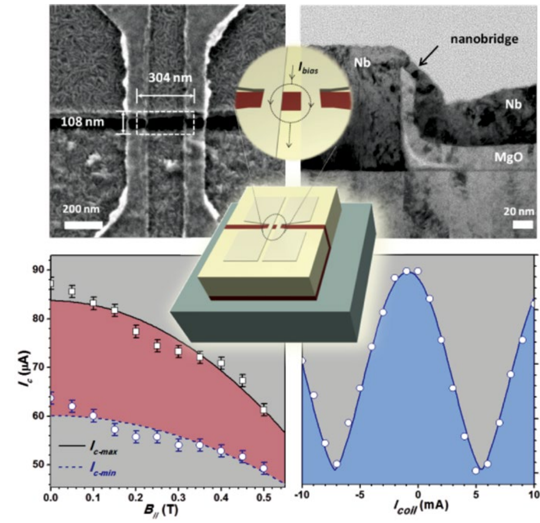
CENSE collaborates with many Chinese institutions in various research fields, such as quantum information processing and satellite laser ranging, to explore advanced applications for SNSPDs. More than 20 SNSPD-based systems were installed for various applications at 10 universities and institutes. These collaborations have produced a series of important results that have enabled significant progress in the field of superconducting electronics.

Homemade SNSPD systems have been applied to quantum key distribution (QKD) experiments and have achieved several world records, including a record distance of 404 km for fiber-based QKD. An SNSPD at a wavelength of 532 nm was applied to a ground station for satellite laser ranging at a distance of approximately 3,000 km, and a new method for time-of-flight few-photon imaging was developed. Among other achievements, CENSE observed quantum fingerprinting, exceeded the classical information transmission limit by using a low-DCR SNSPD, demonstrated time-bin-encoded boson sampling with a fast SNSPD, and realized quantum teleportation over a network by using a high-SDE SNSPD.

In the field of SQUIDs, CENSE proposed and verified novel SQUID chips with electronics, focusing primarily on simplicity, robustness, and targeting real-world applications while maintaining an acceptable noise level. All-NbN SQUIDs were designed and developed with high-quality epitaxial NbN/aluminum nitride (AlN)/NbN Josephson junctions on single-crystal magnesium oxide substrates. Their performance is comparable to that of Nb-based SQUIDs at liquid-helium temperatures; temperature fluctuations do not lead to an appreciable degradation in their performance. Verification of these results has demonstrated the high performance and good temperature stability of the all-NbN SQUIDs. Moreover, CENSE has realized the fabrication of a SQUID magnetometer and gradiometer on a 4-in. silicon wafer based on Nb/Al technology. These technologies show outstanding noise performance—3.5 femtotesla (fT)/$Hz^{1/2}$ for the magnetometer and 0.65 fT/(cm·$Hz^{1/2}$) for the gradiometer—and are beneficial for multichannel application systems. These SQUIDs have been successfully employed in biomagnetism and geophysical applications. Moreover, a new type of Nb nanoSQUID composed of three-dimensional (3D) nanobridge junctions has been developed. Recently, research on nanoSQUIDs has received increased attention because of their applications in the readout of solid-state spin-based qubits and high-resolution scanning SQUID microscopy. However, existing Nb nanoSQUIDs with nanobridge junctions usually exhibit a low magnetic-flux modulation depth (approximately 15%). The improvement of the



Superconducting quantum interference devices (SQUIDs) (*3, 4*). A SQUID magnetometer wafer and packing module (**top left**), and gradiometer wafer and packing module (**top right**). A scanning electron microscope photograph of a SQUID (**bottom**).



Structural imaging and characterization of a 3D niobium (Nb) nanoSQUID (*5*).

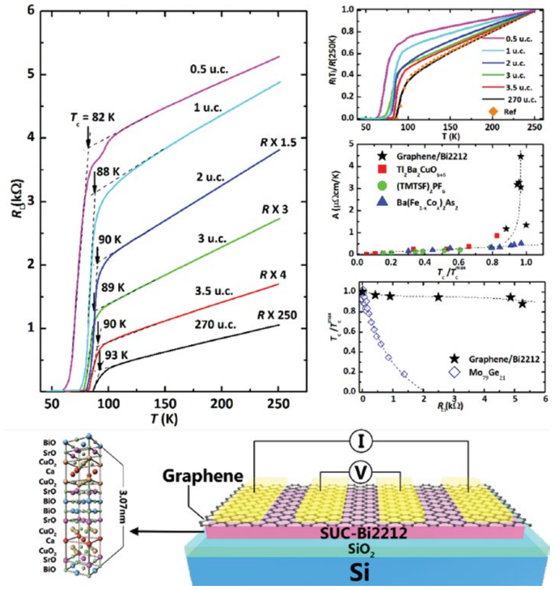
junction-current–phase relation by CENSE led to a significant increase in the magnetic-flux modulation depth (up to 73%). The magnetic flux noise of the device was measured to be as low as 230 $n\Phi_0/Hz^{1/2}$. Furthermore, it can withstand a parallel magnetic field as high as 0.5 tesla, which corresponds to a field in the X band (10 GHz) for electron spin resonance requirements. The 3D Nb nanoSQUID constitutes an important step toward the inductive detection of a single electron spin.

An airborne full-tensor magnetic gradient system was developed by CENSE, and several flight tests were carried out. The system's performance approaches that of the world's best. A superconducting system based on the transient electromagnetic method was also developed, and several profile surveys were undertaken. The results of the profile surveys were supported by the drilling data. The inversion depth exceeded 2,000 m. Several types of gradiometer modules with different baselines and gradient orders were fabricated in an unshielded environment and in a magnetically shielded room.

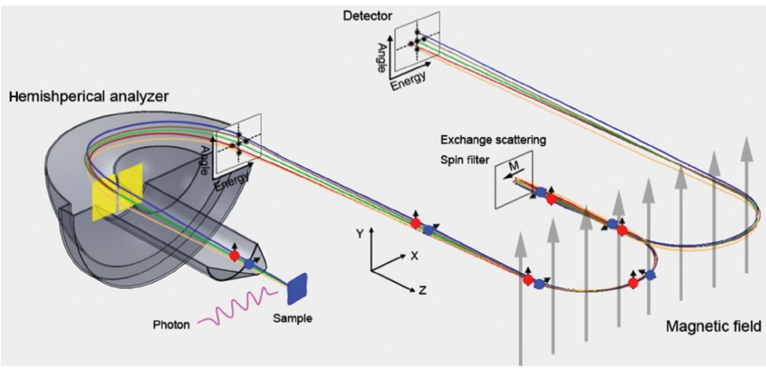
Additionally, CENSE piloted adult magnetocardiography (MCG), fetal MCG (fMCG), and magnetoencephalography signal detection, and set up the first 36-channel MCG system and 4-channel fMCG system in a magnetically shielded room in China. CENSE endeavors to improve system performance and introduce MCG systems for clinical applications. CENSE built the first unshielded ultralow field (ULF) magnetic resonance imaging (MRI) system working in a harsh urban radiation environment. The ULF-MRI group is now developing a low-cost MRI system for biological tissue imaging. They are also working on the design of novel imaging contrast agents, optimization of the prepolarization technique, and exploration of medical applications for the ULF-MRI system.

The mission of quantum materials research at CENSE is to carry out advanced research on the synthesis/fabrication, structure, and physical properties of materials as well as their complex interrelationships, using materials science and condensed-matter physics. The research covers novel functional materials, such as conventional and unconventional superconductors, two-dimensional (2D) atomic crystals, topological quantum materials, and related heterostructures. By studying their atomic/electronic structures and transport and regulation properties, CENSE aims to clarify the underlying mechanisms and correlations between material parameters and device performance, in order to discover new materials with superior properties for device applications. One of CENSE's goals is to provide scientific grounds for the development of new materials, new devices, and new techniques with the aim of generating collaborative innovation in materials science, physics, device engineering, and applications research. Recent breakthroughs include high-temperature superconductivity in ultrathin (half-unit cell) bismuth (Bi)-cuprate superconductors, the interfacial superconductivity of oxide heterostructures, wafer-size single-crystal graphene growth, and the edge chirality control of graphene nanoribbons. CENSE's advanced spectroscopy methods and equipment as well as its micro-/nanoprocessing and characterization facilities greatly extend the scope and depth of its materials research. In combination with theoretical simulations, quantum materials research at CENSE forms a complete innovation chain along with the R&D and application of superconducting devices and circuits.

The novel properties of materials originate from their electronic states and the interactions between electrons. Research on the physical properties of materials at the microscale is based on the characterization of the multiple degrees of freedom of electrons, including their energy, momentum, orbit, and spin. The research area of in situ characterization of electronic structure is based on the Shanghai Integrated Platform for Materials of Energy and Environment (SiP·ME^2) founded by the National Natural Science Foundation of China. The platform aims to develop advanced synchrotron-based characterization methodologies and apply them to a broad range of fundamental and application fields such as superconductivity, magnetism, energy storage, catalysis, and the electronic structure of new functional materials. Currently, CENSE's research area covers in situ X-ray spectroscopy technology, spintronics, novel quantum materials for informatics, strongly correlated electronic systems, surface catalytic reactions, and energy storage materials.



High-temperature superconductivity in graphene/ultrathin $Bi_2Sr_2CaCu_2O_{8+x}$ heterostructure down to a half-unit cell (*6*).



High-efficiency multichannel spin- and angle-resolved photoelectron spectroscopy apparatus measuring simultaneous parallel detection of 6,786 channels (78 x 87) of electron energies, angular momenta, and spins (*7*).

In the future, CENSE, in association with SIMIT, will strengthen R&D into superconducting materials, sensors, and detectors, and promote research on the application and industrialization of existing superconducting quantum device technologies such as SNSPDs and SQUIDs. At the same time, the design and fabrication of superconducting quantum devices and circuits will be further improved. In addition, the development of superconducting ICs and a superconducting computer will soon begin, which will raise the level of R&D of superconducting electronics.

Advanced silicon-based materials and applications

Both SOI wafers and large-scale silicon wafers form the foundation of IC manufacturing. SOI technology in particular is renowned as the "silicon IC technology of the 21st century," owing to its applications in high-speed, low-power-consumption circuits, high-temperature-resistant circuits, micromechanical sensors, and photoelectric integration processes. Moreover, SOI technology is important because of its radiation hardness and its strategic significance in national security and aerospace R&D.

In the 1980s, SIMIT was the first Chinese institute to conduct research on SOI materials and devices, and it continues to take a leading role in this field. SIMIT has gradually built a foundation for SOI technology through technological innovation. In 2001, it incubated the sole SOI manufacturing base in China, Shanghai Simgui Technology Co., Ltd., enabling the industrialization of SOI technology. In 2005, SIMIT realized the key technological breakthrough of bond and etch-back SOI (BESOI) fabrication, and ramped up production at Simgui. Meanwhile, SIMIT also merged BESOI technology with separation by ion implantation of oxygen (SIMOX) technology, and developed a world-class independent intellectual property, Simbond. Applying the Simbond technology, SIMIT produced an SOI material that includes a top silicon layer with a continuously tunable thickness and a buried insulator layer. The mass production of Simbond technology has now been achieved. In 2006, after years of R&D and industrialization, SIMIT was awarded a First Class National Science and Technology Progress Award for "Research and Industrialization of Silicon-On-Insulator (SOI) Materials." In 2007, the SOI research group at SIMIT received the Distinguished Scientific Achievement Award from CAS. Through the development of SOI technology, Simgui has manufactured products that cover most SOI application areas, and their quality and technical capabilities are recognized by prominent international companies. Currently, more than 90% of Simgui products are sold to North America, Japan, Europe, Russia, South Korea, Taiwan, and Singapore, and Simgui has become a supplier for NXP Semiconductors N.V., Toshiba, GlobalFoundries, Vanguard, Hitachi, CSMC Technologies Corporation, and Mellanox Technologies. In 2014, Simgui signed a strategic cooperation agreement with Soitec and initiated international industrial cooperation. In 2015, in collaboration with Soitec, Simgui successfully prepared the first 8-in. SOI wafers using hydrogen-implanted layer transfer technology. Currently, 8-in. SOI wafers are being produced at high volume for radio frequency (RF), power, and silicon photonics applications.

In view of the rapid development of ICs, it was apparent that a smaller feature size would stimulate a greater demand for SOI wafers. Aiming at meeting the demand for fully depleted SOI (FDSOI) materials, SIMIT developed Sim-split technology as an independent intellectual property and successfully produced FDSOI wafers with a controllable thickness. In order to address the issue of reduced carrier mobility in the device caused by shrinking channel length, SIMIT explored a solution to improve carrier mobility in three ways (strain engineering, new channel materials, and hybrid crystal orientation) and successfully developed three high-mobility SOI materials (strained SOI,

Examples of silicon-on-insulator (SOI) wafers fabricated by SIMIT

germanium-on-insulator, and hybrid-orientation SOI). Moreover, aiming at developing SOI materials from 3D to 2D, SIMIT successfully synthesized single-crystal graphene wafers on germanium, building the foundation for developing 2D SOI wafers.

In the future, microelectronic and optoelectronic devices, as well as intelligent microsystems assimilating technology trends such as miniaturization and integration, will continue to be developed. The functions of microsystem chips will become more complex, more diversified, and more easily integrated into other systems. These development trends have spurred a huge demand for heterogeneous integration technology. Heterogeneous integration paves the way for the development of microelectronics in the post-Moore era. SIMIT has conducted R&D of XOI technology (X-on-insulator, where X = a compound or functional thin film) for fabricating silicon-based heterogeneous integrated substrates, and has developed the “lattice cutting” and “heterogeneous interface fusion” processes for integrating dissimilar materials with a silicon (Si) substrate. SIMIT has achieved fabrication of different types of single-crystal thin films with heterogeneous integration, including silicon-based compound semiconductors (III–V, wide-bandgap semiconductors) and silicon-based functional films (piezoelectric and ferroelectric film).

SOI devices have an enhanced immunity to single-event effects and transient radiation effects compared to their bulk Si counterparts; however, the introduction of buried oxide leads to severe total ionizing dose (TID) effects. To increase radiation tolerance to TID effects, an excellent method for the fabrication of highly crystalline, high-quality radiation-hardened SOI wafers has been proposed, with independent intellectual property rights. These modified SOI materials show superior performance, and their technical specifications are comparable with those of commercial 8-in. SOI wafers. The total dose radiation tolerance of hardened SOI is 500 krad(Si), which can be substantially improved to 1 million rad (Mrad)(Si) with further modification. This technique brings the advantages of a strong process and product expansibility by adjusting implantation parameters. The successful mass production of radiation-hardened SOI wafers has provided a solid foundation for developing radiation-hardened SOI ICs for space applications.

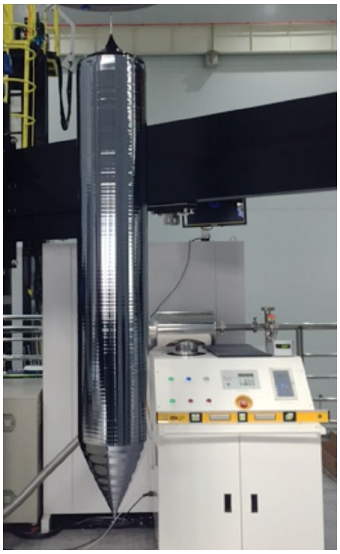
Faced with the urgent demand for a new generation of

Signing of a strategic cooperation agreement between Shanghai Simgui Technology Co., Ltd., and Soitec

The first independently developed 8-in. radiation-hardened silicon-on-insulator (SOI) wafer, manufactured by SIMIT

Successful launch of an SOI-based “SIMIC” security chip (inset) onboard the Beidou Navigation Satellite

information technology for high-speed optical communication and optical switching in silicon ICs, silicon-based photonics—which could substitute optical interconnects for metal interconnects and use photonics as a medium for transmitting data between chips and devices—is inevitable in the development of computer systems and communication equipment characterized by broadband, high-speed, large-capacity, and large-scale parallel processing. SOI materials are an ideal platform for manufacturing complementary metal-oxide semiconductor (CMOS)-compatible silicon-based photonics devices, and they are a solid foundation for the rapid development and industrialization of silicon-based photonics. Together with Hua Hong Semiconductor Limited and Shanghai Industrial μTechnology Research Institute (SITRI),



Shanghai Zing Semiconductor Technology Co., Ltd., successfully produced the first 300-mm single-crystal ingot in China.

SIMIT established 0.13-μm silicon photonic devices and an optoelectronic integrated technology platform compatible with CMOS processes. The research group developed silicon nanowire optical waveguides, the transmission losses of which to the transverse electric and transverse magnetic modes are 2.4 + 0.2 dB/cm and 0.59 + 0.32 dB/cm, respectively. Furthermore, SIMIT developed a variety of high-performance silicon-based optoelectronic devices such as grating couplers, low-loss filters, multimode interference splitters/combiners, and other passive devices as well as adjustable optical attenuators, high-speed silicon-based photoelectric modulators and detectors, and other active devices.

In terms of photonics integration, the research team realized a monolithic, integrated, arbitrary microwave waveform-generation function underpinned by silicon-based integrated photonics technology, in order to overcome the shortcomings of the conventional microwave photonics system built with discrete devices—such as its large volume, high power consumption, and impact on the external environment. Signal modulation, an adjustable delay, a signal channel, and other functions are integrated on the same chip to create a lightweight, low-power-consumption, multichannel microwave photonic chip. To overcome the diffraction limitation of current photonics integration and propose new principles and schemes for realizing high-density, ultra-large-scale photonics integration, the research team developed a new optical manipulation system based on a silicon nanopillar structure, which broke the optical diffraction limit. In addition, an all-silicon, single-row cylindrical array with a high depth-to-width ratio and high surface quality has been developed.

Silicon wafers are the cornerstone of IC manufacturing and an important raw material that dictates the performance of ICs. In 2014, SIMIT participated in the establishment of Shanghai Zing Semiconductor Technology Co., Ltd. (ZingSemi), which was committed to providing a complete set of 12-in. silicon-wafer mass production technologies for the 40 nm–28 nm process, including single-crystal growth, wafer processing, epitaxial wafer growth, wafer analysis, and wafer characterization. The company was committed to setting up a 12-in. semiconductor silicon-wafer production base in China to fully meet the urgent need for 12-in. silicon wafers in China's IC industry. Thus far, ZingSemi has applied for 480 patents, of which 60 have been issued. In 2016, it successfully produced the first 300-mm single-crystal ingot in China. ZingSemi is committed to manufacturing and supplying key materials for the IC industry in China, thus securing the supply chain and bringing its technology up to global standards.

Going forward, SIMIT plans to develop 12-in. silicon wafers and 12-in. FDSOI wafers, and also to explore wafer-scale high-mobility SOI materials, all with the aim of meeting future demand for microelectronics technology. It will lead the development of advanced microelectronics processing in China and undertake the application of FDSOI technology to IoT and vehicle electronics. Moreover, SIMIT will develop 8-in. RF SOI wafers and 8-in. power SOI wafers, and explore technologies for integrating nonsilicon and wide-bandgap semiconductors such as SiC and gallium nitride (GaN) with silicon and SOI architectures. Simultaneously, SIMIT will develop special techniques to create radiation-hardened SOI wafers and manufacture highly reliable IC chips to meet the demands of IC chip applications in special, high-radiation environments. Additionally, SIMIT will build a first-class, radiation-hardened R&D center in China; realize the coordinated development of radiation-hardened SOI materials, production processes, devices, chips, and system applications; and develop radiation-hardened chips for aerospace applications. Furthermore, SIMIT will integrate silicon-based photonic devices with circuits in a single chip, using mature CMOS manufacturing techniques. With silicon photonic chips, digital information can be transmitted using optical signals; consequently, the bottlenecks related to the interconnections in high-performance computers and high-end computer processing units can be overcome. Through collaborative innovation, SIMIT is striving to be the world's leading large-silicon wafer producer.

Special broadband wireless communication technologies and equipment

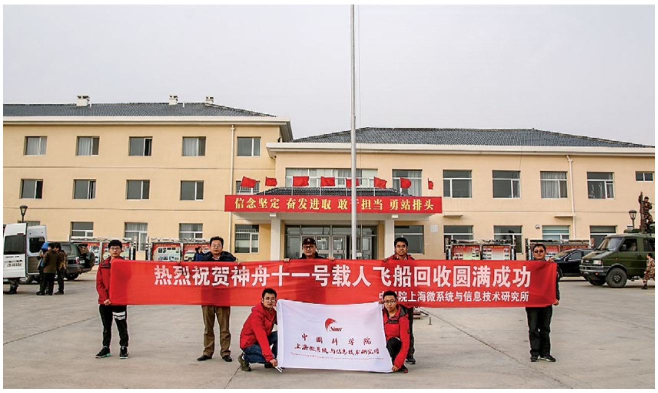
Wireless communication technology is one of the most important of China's national core research areas. It can enhance the competitiveness of the country's S&T research and development, and greatly promote sustainable economic growth. Along with the rapid spread of broadband wireless communication technology, SIMIT is also focused on building highly specialized broadband wireless communication networks and related equipment that meets special demands, such as those of national security and the railway, electricity, and transportation industries.

Special broadband wireless communication equipment

In 2008, SIMIT set up the Broadband Wireless Technologies Laboratory (BWTL). As a leading special communication network solutions provider, BWTL focuses on the challenges of mission-critical communication scenarios, such as the absence of infrastructure, reliable high-speed transmission, massive node access, ultra-high-speed mobility, self-managing and self-healing, flexibility and scalability, and high security. Traditional

Testing a special broadband communication system during a disaster relief effort in Wenchuan City, Sichuan Province

Retrieving data from the Shenzhou XI spacecraft recently returned to Earth



Celebrating the return of the Shenzhou XI spacecraft

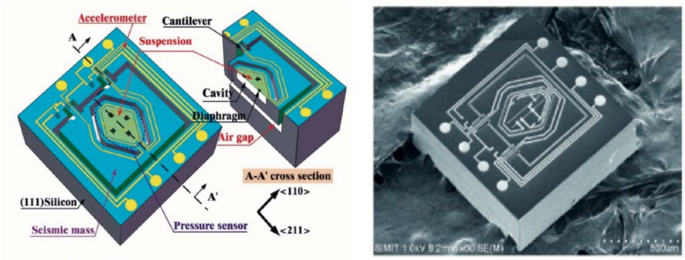
civil or commercial broadband communication technology focuses on optimization for low mobility and short-range transmission performance, and cannot meet the deployment needs of special industries that require complex, multipath high-speed/high-mobility capabilities and can only operate on authorized frequencies. Special broadband wireless communication systems aim to provide reliable wireless communication in complicated geospatial environments as well as electromagnetically complex environments.

BWTL has taken the lead in research on a new generation of mobile communication in China, proposing discrete Fourier transform-spread generalized multi-carrier (DFT-S-GMC) transmission solutions for a new generation of broadband wireless mobile communication using patented technology. It has developed two broadband wireless access systems based on millimeter-wave and time-division long-term evolution (TD-LTE), and made breakthroughs in some key technologies for a new generation of broadband wireless emergency communication. BWTL has also drafted national broadband wireless multimedia standards, participating in the international 4G standardization process and completing the integration and testing of the first Chinese 4G system. In addition, BWTL has focused on special broadband wireless communication for the future, and continues R&D on smart grid–specific wireless communication, railway location information systems, and wireless communication utilizing orbital angular momentum. BWTL will actively participate in and cooperate with standardization efforts worldwide, further develop future broadband wireless mobile communication systems, and strive to become an important base for R&D, technology innovation, and the industrialization of special broadband wireless communication technology and equipment.

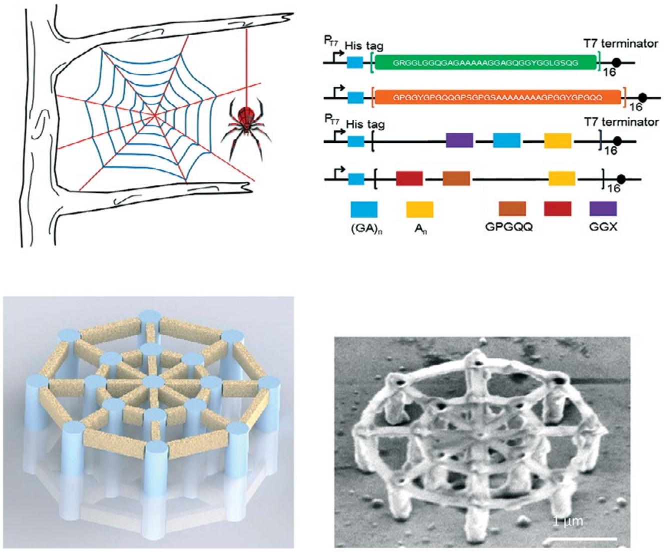
By leveraging advanced 4G/5G wireless transmission technologies combined with in-house intellectual property covering DFT-S-GMC transmission, software-defined ad hoc network architectures, and artificial intelligence spectrum management methods, BWTL can assure optimal, secure wireless communication. It has designed and developed every component of the technology while also adjusting to the ever-changing priorities and challenges of mission-critical communication. Every aspect and component of BWTL's products are designed to allow maximum flexibility and scalability. Versatile network topologies and product portfolios cater to every deployment and project scope, from small to large scale, with the greatest flexibility and reliability. BWTL develops and delivers special network solutions for many application areas, including military communication, railway transportation, disaster relief and public safety, and security and surveillance.

In the area of disaster relief and public safety, BWTL/SIMIT has been involved in many activities since 2008, and has established several emergency broadband wireless communication networks and 24-h long-distance wireless monitoring systems. For example, BWTL/SIMIT played a key role in providing technology for the 2008 Wenchuan earthquake, the 2010 Yushu earthquake, and the 2010 Shanghai World Expo. On November 18, 2016, wireless broadband communication technology was successfully used in the rescue command communication support system for the return of the Shenzhou XI spacecraft, the vehicle used for China's longest manned space mission. With eight helicopters and multiple ground systems, SIMIT built a search communication security system for the main landing area, which captured the first onsite picture for the Beijing Aerospace Control Center.

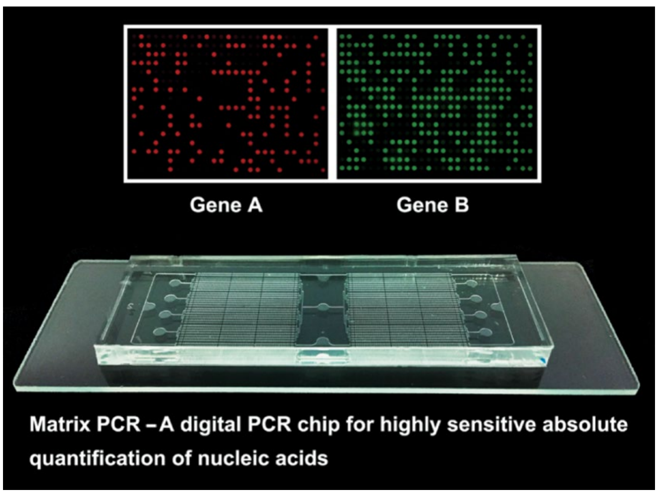
For China's railway transportation industry, SIMIT has formed a railway location information system that covers the full range of dynamic and static location information on targets such as railroad tracks, trains/vehicles, and people and facilities; developed train/cargo/human location services (positioning accuracy down to the centimeter level) and antitheft functionality for facilities; improved transport production efficiency; and ensured transport and personnel safety. The system is currently being verified and applied at the Guangzhou Railway Bureau. SIMIT has also completed several electricity projects with the State Grid Corporation and China Southern Power Grid Co., Ltd., providing solutions for automatic



Single-wafer, single-side fabrication of a multifunctional pressure sensor into an accelerometer hybrid sensor using a micro-openings inter-etch and sealing technique (*8*).



Examples of 3D biomimetic bionanostructuring on genetically engineered spider silk to create specific shapes or functions on demand (*9*).



Micro-/nanobiosensors using matrix polymerase chain reaction (PCR) technology to monitor cancer biomarkers

power distribution and video monitoring of power transmission lines over thousands of kilometers.

In the near future, SIMIT will further focus on special broadband wireless communication and continue their R&D of smart grid–specific wireless communication, railway location information systems, and wireless communication utilizing orbital angular momentum.

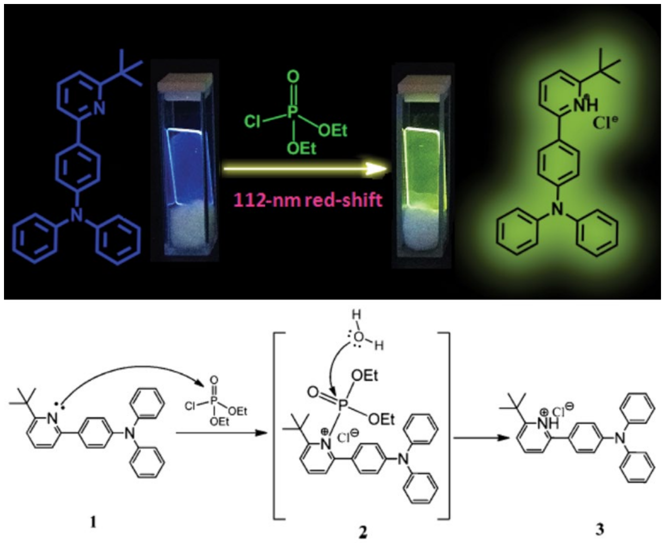
Micro- and nanotechnologies for sensors and transducers

The State Key Laboratory of Transducer Technology ($SKLT^2$), with its south branch located at SIMIT, was approved for construction by the National Planning Commission in 1987 and officially opened in 1989. It was the first State Key Laboratory founded in China that focuses on transducer technologies based on microelectronics and micro-/nanofabrication. The major research theme of $SKLT^2$ is emerging micro- and nanotechnologies for sensors and transducers (MNTST), which covers major topics within this multidisciplinary field, and impacts many real-world applications ranging from consumer electronics and medical instrumentation to security systems and environmental monitoring. The main research activities at $SKLT^2$ include the development of micro-/nanomanufacturing techniques, new sensing materials and mechanisms, advanced sensing devices, and integrated microsystems. The goal of $SKLT^2$ is to meet emerging demands for transducer technologies for national security, aerospace, energy, the automotive sector, industrial applications, health care, and consumer electronics, among other areas. In 2011, $SKLT^2$ received the second prize of the Shanghai Science and Technology Progress Award for their work entitled "Trace Detection of Explosives Using Fluorescence Chemical Sensors." In 2012, it received the second prize of the National Science and Technology Progress Awards for "Three-Dimensional High-Density Packaging Technology of RF Electronic Systems and Its Applications," and the second prize of the State Technological Invention Award for "Key Technologies and Design Methods of MEMS 3D Manufacturing Based on Process Selectivity." Furthermore, $SKLT^2$ received the 2015 second prize of the Shanghai Technological Invention Award for "Key Technologies of High Sensitivity Photoelectric Sensor Chips and Portable Embedded Spectrometers."

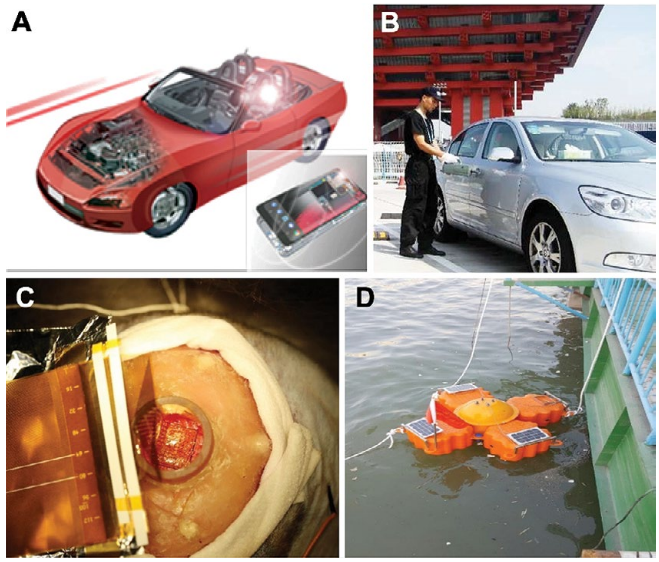
$SKLT^2$ was involved in early efforts to develop key technologies in the field of MNTST, and has achieved breakthroughs in important scientific and technical areas within the following two major research directions:

1. The development of new techniques and strategies for micro-/nanofabrication. $SKLT^2$ has developed a silicon-based, single-sided fabrication technique, called "micro-openings inter-etch and sealing" (MIS), which is compatible with current IC foundry protocols. In addition, three innovative microfabrication processes have been developed based on MIS, including packaging-stress-suppressed suspension (PS^3), thin film under bulk (TUB), and pressure sensor into accelerometer (PinG). They can be used individually or in combination to create 3D, multilayered, and functional MEMS structures. These processes are designed for high-yield, low-cost volume production of MEMS devices and are compatible with standard fabrication processes in original equipment manufacturer IC foundries. A facile through-silicon-via (TSV) process has also been developed using wafer-level liquid-metal injection via a filling method. The combined effects of capillary action and liquid bridge rupture allow rapid MEMS packaging, which effectively shortens the TSV filling time from several hours to several minutes. Additionally, a novel method for precise 3D bionanostructuring—termed "protein bricks"—has been developed to create biologically functional, hierarchical, and heterogeneous micro-/nanostructures with specific shapes and functions on genetically engineered proteins. The unique combination of protein-based biomaterials and ecofriendly micro-/nanofabrication techniques offers extensive versatility for a variety of applications that require devices to be produced in a "green" way with customizable biofunctions and accurate nanoscopic geometries. This new biomanufacturing paradigm serves as a promising route to biomimetic 3D micro-/nanomanufacturing, to complement and potentially disrupt current bionanofabrication techniques including both top-down (based on lithographic methods) and bottom-up (via self-assembly, such as DNA origami) approaches, owing to its capacity to fabricate multiscale structures with facile functionalization.

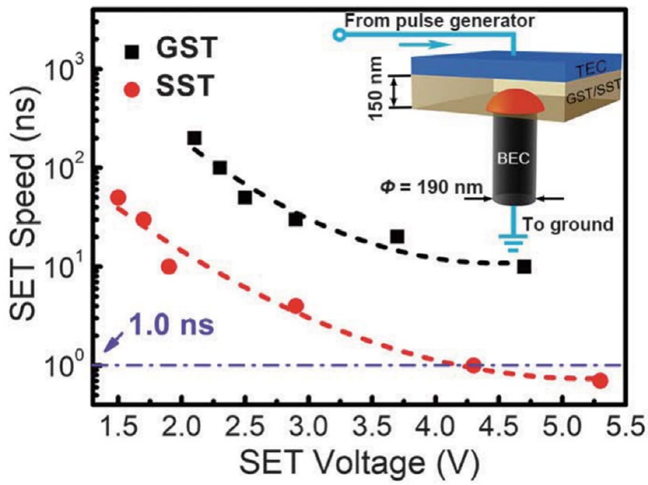
2. The discovery of new materials and mechanisms for sensing applications. SKLT² has been working on ecofriendly micro-/nanofabrication techniques using biocompatible and biodegradable biopolymers (e.g., naturally extracted and/or genetically engineered proteins) as the resist materials for the precise patterning of functional sensing materials and structures using standard lithography techniques such as electron-beam and ion-beam lithography. The electron- or ion-regulated nanoscale polymorphic transitions in protein-based bioresists are revealed by near-field infrared imaging and nanospectroscopy at resolutions approaching the molecular level. The ability to locally probe nanoscale protein-structure transitions combined with nanometer-precision lithography offers fine control of the structure of protein resists in both positive and negative tones as well as in two and three dimensions. SKLT² has further developed a method for creating a new class of optical devices that can dissolve/degrade into the surrounding environment or the human body at controlled rates, referred to as "physically transient micro-/nano-optics," for information concealment and medical implantation. Moreover, SKLT² has been actively engaged in the early detection of cancer and has developed a series of micro-/nanobiosensors that are capable of multiparameter monitoring of cancer biomarkers (such as nucleic acids, proteins, cells, and exosomes) at single-cell and single-molecule levels using a matrix polymerase chain reaction. These microfluidic-based sensors provide a solution for diagnosing cancer patients at a low cost, providing rapid analysis of fluids and nonturbulent flows in a device with a small footprint. SKLT² has also established a comprehensive set of methods and strategies for developing fluorescence-based optical chemical sensors using organic semiconductors as the key sensing element for the portable, multichannel, and ultrasensitive trace detection of explosives and nerve agents. These sensors were successfully employed at several important public events, including the Shanghai World Expo 2010, the 2016 G20 Hangzhou Summit, and the 2017 BRICS Summit. Furthermore, a "cantilever-based lab-on-a-chip" strategy has been developed to quantitatively investigate the molecular interactions between a functional material and biochemical molecules (from the perspective of the "material genome") using a comprehensive set of thermodynamic/kinetic parameters such as enthalpy, Gibbs free energy, and activation energy, which are extracted from the sensing data measured by resonant microcantilevers. A series of functional materials has also been identified and optimized for toxic gas capture and/or detoxification applications using cantilever-based microgravimetric analyzers.



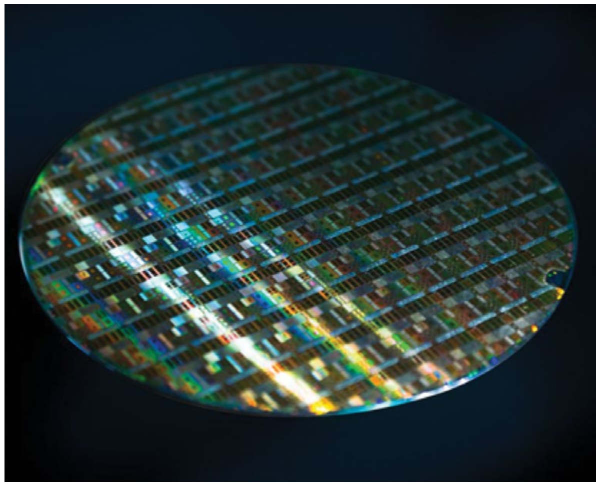
Efficient fluorescent sensor for detection of nerve-agent mimic diethyl chlorophosphate using intramolecular charge transfer (*10*).



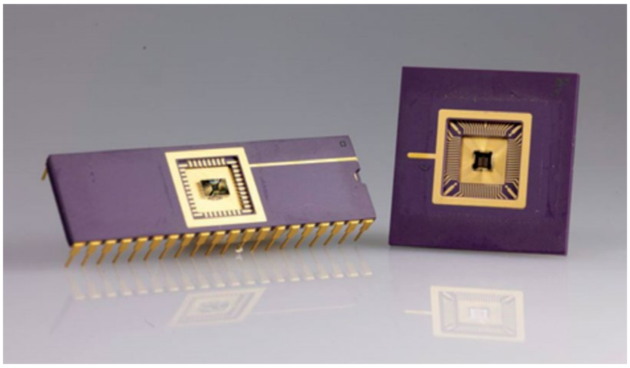
Examples of typical applications based on the four major research areas within SKLT²: (A) Consumer electronics, (B) security, (C) medical instrumentation, and (D) environmental monitoring.



Data from a research paper published in *Science* showing 700-ps SET speed in Sc-Sb-Te phase-change materials (*16*). GST, GeSbTe (germanium-antimony-tellurium); SST, Sc–Sb–Te (scandium-antimony-tellurium); TEC, top electrode contact; BEC, bottom electrode contact.



Phase-change random-access memory (PCRAM) units on a wafer



Packaged PCRAM chips

Mass-produced PCRAM chips used in printer ink cartridges

SKLT[2] has been a pioneering institution in research on MNTST and has contributed significantly to the advancement of transducer technologies. Currently, SKLT[2] is working on important scientific research related to emerging micro-/nanotransducer technologies, including the design and manufacture of micro-/nanosensors and transducers, MEMS and NEMS, the sensing mechanisms of nanomaterials, and integrated transducing microsystems and chips. In the future, SKLT[2] will continue its research with an expanding interdisciplinary team that embraces challenges with passion and creativity, to pursue fundamental science and meet the practical demands in the growing MNTST field.

Phase-change random-access memory (PCRAM) and applications

IC chips form the foundation of all information technology systems and therefore play a key role in the domestic economy and national safety. One third of all IC chips are used to store information, either temporarily or permanently. At present, dynamic RAM (DRAM) and Flash dominate the global market, accounting for 95% of memory storage chips sold. However, neither of these technologies are perfect: DRAM memory can be affected by external charge because of the smaller number of electrons in its capacitor relative to other forms of storage, while Flash faces serious crosstalk problems during operation, shortening its lifespan. These problems become more serious as the feature sizes on the chips shrink and approach a critical limit below 28 nm. Furthermore, storage technologies such as DRAM and Flash are incompatible with advanced CMOS technologies. Therefore, efforts are underway worldwide to develop new, non-volatile storage technologies that are compatible with advanced CMOS technology and have good scalability, 3D integration ability, fast operation speed, low power consumption, and long life. Phase-change RAM (PCRAM) shows promise, because it offers good scaling performance, fast write and erase speeds, 3D integration, and good compatibility with advanced CMOS technology. Thus, it is expected to become the most promising next-generation storage technology for mass production.

SIMIT began conducting PCRAM research in 2003 for three main reasons: First, PCRAM has the best overall properties for a storage technology. Second, it is expected to be the most promising storage technology for mass production in international semiconductor development. And third, PCRAM is a nanoelectronics device, which aligned well with China's promotion of nanotechnology as a national development strategy at that time. SIMIT, together with Semiconductor Manufacturing International Corporation (SMIC), established a technology platform for 8- and 12-in. industrial-level PCRAM chip R&D, and achieved the integration of standard 0.18-μm/0.13-μm/40-nm PCRAM chips with standard CMOS technology. In 2008, SIMIT created China's first fully integrated, functional 8-Mbit PCRAM (the world's first embedded PCRAM), and by 2016, more than 16 million chips for printer consumables had been shipped. By 2017, the bit yield of 40-nm PCRAM chips was improved to over 99.99%, and raw 64-Mb chips were being tested in advanced information systems.

SIMIT has a research group of over 100 staff, conducting studies from basic research to engineering verification. The group has over 15 years of experience in PCRAM materials, structure, technology, testing, and circuit research. Furthermore, they have published two books in the PCRAM field and 410 papers in Science Citation Index journals, including *Science* and *Nature Communications*, and have applied for 344 patents, including 13 in the United States. Of these patents, 242 have been granted, including eight in the United States.

For a storage technology to be competitive in the market, it must offer high-density storage with high-speed read and write materials and circuits. By designing metal-centered octahedra, SIMIT developed scandium-antimony-tellurium (Sc–Sb–Te) and titanium-antimony-tellurium (Ti–Sb–Te) materials. The discovery of Sc–Sb–Te enabled reversible write and erase speeds of less than 1 ns (700 ps), and the power dissipation was 90% less than that of a mass-produced germanium-antimony-tellurium (Ge-Sb-Te) alloy, reported recently in *Science* (*11*). In the Ti–Sb–Te system, the Ti atoms partially substitute for Sb atoms in the hexagonal Sb_2Te_3 lattice and form $TiTe_2$ nanolamellae at grain boundaries, acting as nucleation centers and nanothermal insulators allowing for high speed and low power consumption properties. The results were published in *Nature Communications* (*12*, *13*). These breakthrough discoveries, accompanying the successful design of the high-speed readout circuit (US8947924), have greatly helped in the development of advanced storage technology in China.

For memory cells organized in an array, a method to select individual memory cells is necessary for reading and writing. In PCRAM, the density of memory cells is primarily determined by the size of the memory-cell selector. An Ovonic threshold switching (OTS) selector is one promising candidate for PCRAM owing to its large drive current. Researchers at SIMIT have successfully prepared an OTS device (*14*) and designed a 3D PCRAM circuit (*15*). In the future, SIMIT plans to develop one selector–one resistor (1S1R) single and integrated nanotechnology compatible with CMOS technology using a high-density crossbar structure, and further integrate them with advanced logic processes to achieve high-density storage chips.

Further PCRAM research at SIMIT will be extended to include the following aspects:

1. Basic research on PCRAM: first-principle calculations, the development and engineering of new phase-change materials, high-density 3D switching and memory devices, and brain-inspired computing;
2. PCRAM chip design, testing, and application: 130-/110-/40-/28-nm circuit design, chip technology design, an independent test platform and 8-/12-in. test systems, and chip package testing and application;
3. 8-in. and 12-in. PCRAM process development: development of nanofilling, polishing, and etching; development of single processes such as 1S (one selector), 1R (one resistor), nanoelectrodes, and dielectric coatings; and integration and optimization of 1S1R processes.

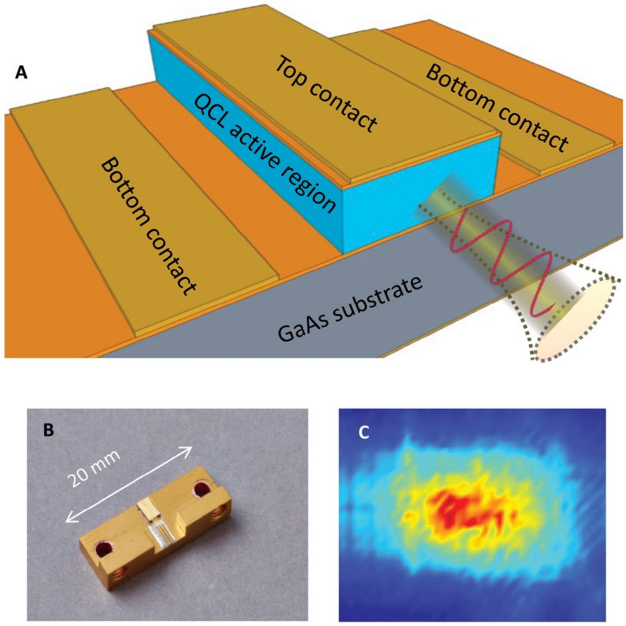
Going forward, SIMIT will focus on IoT, consumer electronics products, and national information security. These fields require a new generation of high-density memory chips that will include new materials, new structures, chip integration, and novel applications. Innovative research will comprise the screening of new low-power, high-speed phase-change memory materials; investigation of the physical nature and intrinsic properties of these materials; development of confined structure technology; development of OTS materials and devices; and clarification of the physical nature of nonlinear carrier transport. Finally, PCRAM chip products based on 130-/110-/40-/28-nm process technologies will be developed to be competitive in the international market, particularly for applications in IoT or smartphones.

Terahertz (THz) solid-state technologies

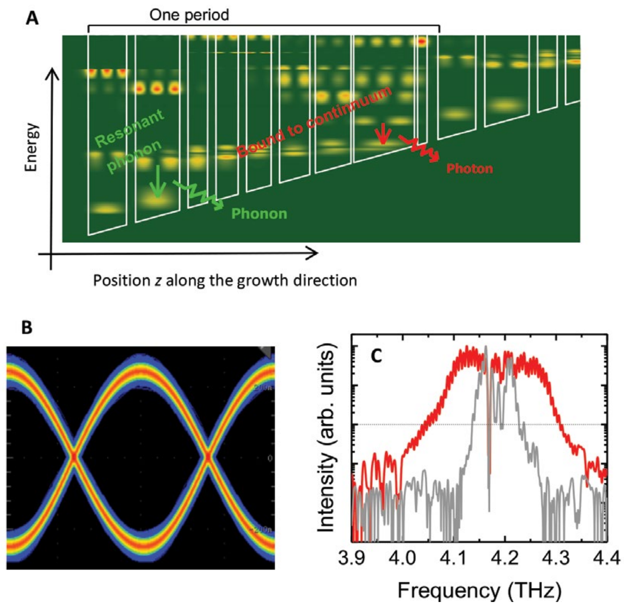
Terahertz S&T has attracted much attention in the past two decades. The THz region is defined as the frequency range from 0.1 THz to 10 THz (corresponding to wavelengths ranging from 30 μm to 3000 μm or photon energies ranging from 0.41 meV to 41 meV), located between the mid-infrared and submillimeter-wave bands. Because of the unique properties of THz waves, they have been applied in important research areas such as the investigation of the properties of semiconductor and high-temperature superconducting materials, tomography, gene discovery, cellular imaging, chemical and biological analysis, broadband communication, security imaging, and nondestructive detection of biological tissues. The study of radiation sources, detectors, and their applications in the THz band will promote the development of THz research and potentially solve major challenges in THz solid-state electronics and circuit technology.

SIMIT is one of the earliest institutions to conduct THz research in China. Although many proof-of-concept experiments have been carried out demonstrating potential applications of THz technology, the lack of compact and convenient devices for the generation and detection of THz waves needs to be addressed before widespread applications become a reality. SIMIT carries out research on THz radiation sources, detectors, and communication as well as imaging applications based on THz photonic and electronic devices. In 2010, with the approval of CAS, the CAS Key Laboratory of Terahertz Solid-State Technology was established with the support of SIMIT. This laboratory has become a leader in the THz research field in China, establishing a complete process and characterization platform for THz solid-state devices and making significant progress in building THz radiation sources and detectors. SIMIT's achievements in the area of THz quantum devices and semiconductor physics won the second prize of the Shanghai Natural Science Award in 2015.

SIMIT carries out both theoretical and experimental research in the field of THz photonics. An impact ionization model of THz radiation has been developed, and a hypothesis



Terahertz (Thz)-based technologies developed at SIMIT. (**A**) Schematic of a single-plasmon waveguide THz quantum cascade laser (QCL). (**B**) Photograph of THz QCL mounted on a copper base. (**C**) Typical far-field pattern of THz QCL.



A THz quantum cascade laser (QCL) frequency comb (*17*). (**A**) Calculated band structure of laser active region. (**B**) Eye diagram used to measure coherence of the modes. (**C**) Homogeneous THz spectral spanning of the laser comb under radio-frequency modulation.

has been proposed to explain the observation that the THz absorption coefficient varies with radiation intensity. The first domestic high-performance THz quantum cascade lasers (QCLs) and THz quantum-well detectors were built and applied in the fields of THz communication and imaging. The successful development of THz quantum-well-detector light-emitting-diode (LED) devices has overcome the challenges of THz detector arrays, and enables THz focal-plane pixelless imaging technology. Utilizing THz QCLs, SIMIT developed an engineering prototype linkage with real-time imaging and spectrum analysis, which can acquire THz images and spectra of dangerous goods. SIMIT also developed a THz modulation circuit and signal processing circuit to allow for real-time audio- and video-signal transmission.

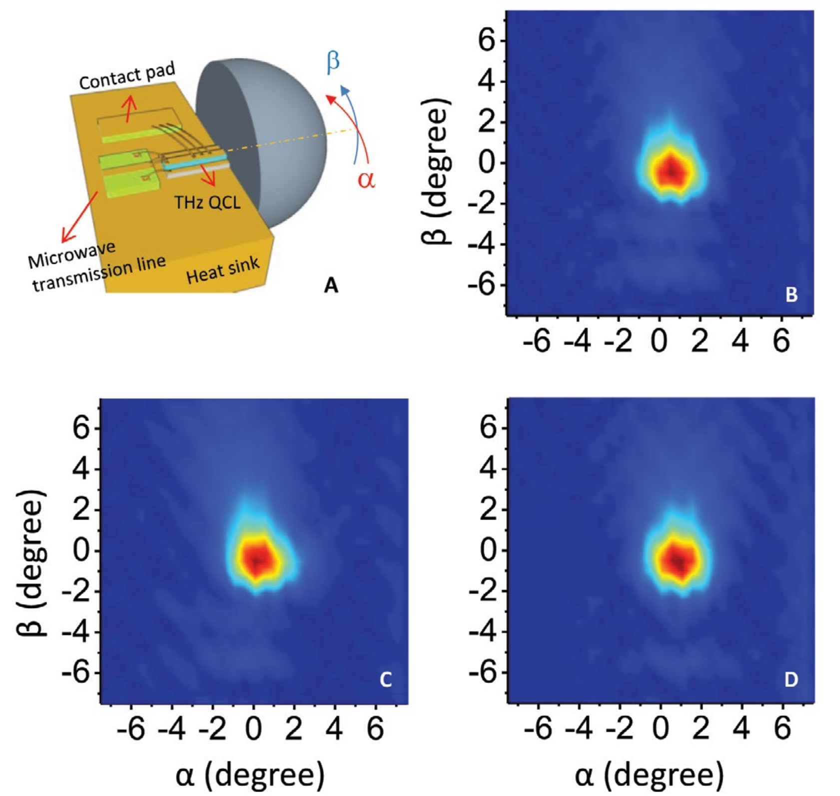
In the fields of THz frequency combs and high-speed THz mixers, SIMIT has recently undertaken innovative research and obtained important results. Using high-performance THz QCLs with a hybrid active region design, SIMIT successfully demonstrated the application of THz frequency combs in QCLs. Furthermore, by employing RF modulation, the THz QCL frequency comb could continuously span over 330 GHz (8% of the central frequency), a record for QCLs with a bound-to-continuum active region design. SIMIT researchers, using the broadband frequency comb, also demonstrated THz spectroscopic applications such as the transmission measurement of a gallium-arsenic (GaAs) etalon as well as spectral identification of ammonia gas. In addition, by exploiting a microwave transmission line, we showed that a THz quantum-well photodetector (QWP) can work as a high-speed frequency mixer. The THz QWP mixer shows an intermediate frequency bandwidth of 6.2 GHz. We successfully measured the optical intermode beat note of a long-cavity THz QCL by employing this mixer. The high-speed QWP mixer was also used for imaging applications. The main advantage of this technique is that the frequency can be downconverted from the THz to the GHz range; therefore, the signal can be easily amplified, filtered, and read using mature microwave technology.

SIMIT has been conducting research on micro- and millimeter-wave solid-state electronics technology since the 1990s. At the beginning of the 21st century, SIMIT took the initiative to develop a K_a-band miniaturized anticollision radar in China, and has carried out R&D of GaAs monolithic millimeter-wave ICs since 2003. At present, K-, K_a-, V-, E-, and W-band series of monolithic millimeter integrated circuit (MMIC) chipsets, for which SIMIT holds intellectual property rights, have been manufactured and applied to millimeter-wave communication and detection systems. Additionally, SIMIT has produced China's first 60-GHz communication chipsets based on vector modulation technology, and an MMIC chip applied to 5G communication has been successfully supplied to Huawei Technologies Co., Ltd. SIMIT also successfully installed a K_a-, V-, and W-band miniature radar detector. Furthermore, SIMIT has manufactured patented human body security inspection imaging equipment, called SimImage, which won the silver award at the 2016 China International Industry Fair. SIMIT successfully completed the transfer of this technology from research to commercialization. SIMIT also performed research on THz solid-state electronic devices and circuits, Schottky diode devices, and related circuits based on GaAs and indium phosphate materials. The knowledge derived from this work allowed for the fabrication of an integrated mixer, a frequency multiplier circuit, and a module for THz imaging using THz solid-state frequency multiplication chain technology, based on Schottky diode technology. The relevant indexes—such as cutoff frequency and junction capacitance—have reached an advanced level by international standards, and achievements include the construction of a 0.36-THz imaging system.

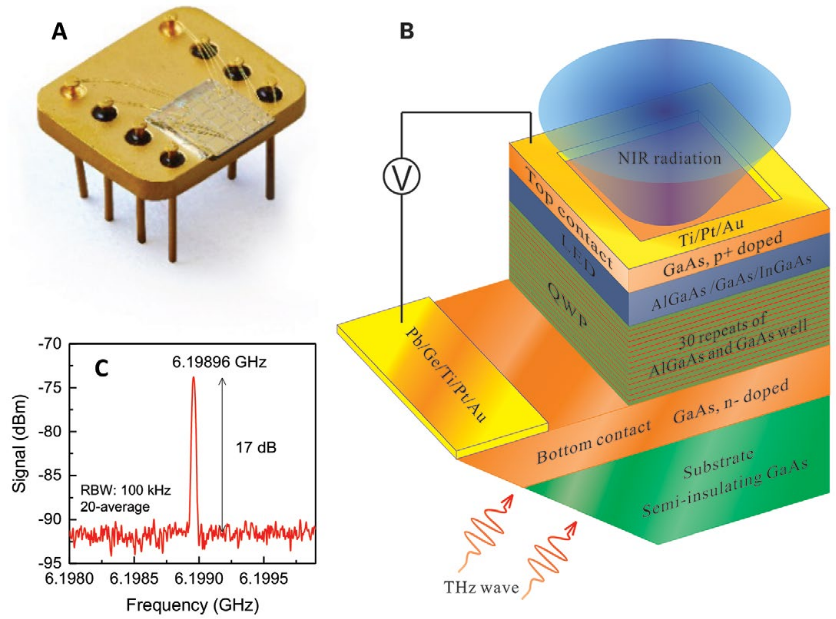
In the future, through cutting-edge research based on high-performance THz QCL frequency combs and fast THz QWPs, SIMIT plans to systematically investigate the saturation absorption, two-photon effect, and fast relaxation process in new materials illuminated by strong THz radiation. This research will provide a foundation for developing new functional devices operating in the THz range. Regarding industrialization, SIMIT will continue development of compact, high-performance THz QCLs, THz QWP modules, and systems for security imaging and space applications, and will promote market-based applications of SimImage millimeter-wave human body security inspection imaging equipment.

Brain-inspired chips and bionic vision

The field of brain science is currently attracting intense international competition. As a major application in this field, brain-inspired intelligence research aims to design formats that can simulate or even transcend human intelligence by emulating neural pathways, endowing a machine with the ability to actively acquire information, formulate concepts, perform analyses, and make decisions in a complex environment. As opposed to artificial intelligence, brain-inspired intelligence is based on human traits and characteristics. Its development is expected to lead to a new era of advanced machine intelligence. As part of SIMIT's cutting-edge research in information science, it has been investigating brain-inspired intelligence since 2012 and has gathered an international research team. The team began its study by imitating the human visual system, and now forms the backbone of the CAS Center for Excellence in Brain Science and Intelligence Technology

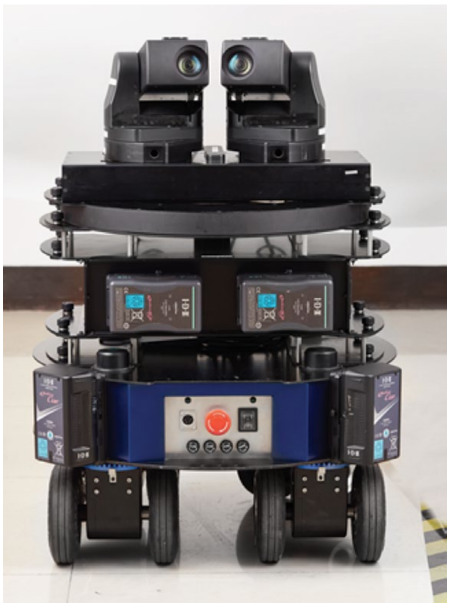


Narrow beam divergence of double-metal terahertz (Thz) quantum cascade lasers (QCLs) (*18*). (**A**) Schematic illustration of a QCL mounted with a silicon lens. **B**, **C**, and **D** show the measured far-field beam patterns of the laser at different drive currents.



A THz quantum-well photodetector (QWP) (*19*, *20*). (**A**) Photograph of THz QWP showing a 45° edge facet. (**B**) Schematic of a THz QWP-light-emitting diode (LED) device. (**C**) Intermode beat-note spectrum of THz QCL measured using a fast THz QWP. NIR, near infrared; Ga, gallium; As, arsenic; Ti, titanium; Pt, platinum; Ac, actinium; Al, aluminum; In, indium; dB, decibel; dBm, decibel-milliwatts; RBW, resolution bandwidth.

SimImage millimeter-wave human-body security inspection imaging equipment



Bionic vision demonstrated on a mobile robot

An example of bionic human eyes

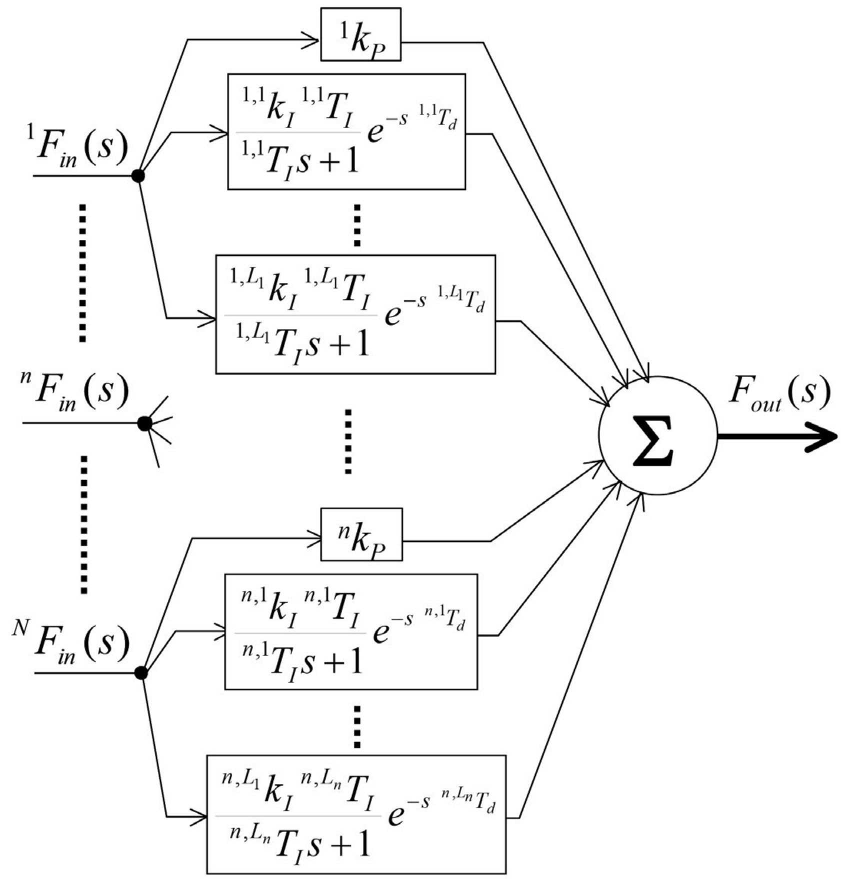
(CEBSIT). Moreover, SIMIT also plays a critical role in the "Shanghai Brain-Intelligence Engineering" group, which undertakes research on human bionic vision systems and vision intelligence. To solidify SIMIT's contribution to the overall national strategy for brain research and provide reliable technical support in bionic vision and brain-inspired intelligence, it created the Bionic Vision System Laboratory.

The human visual system is an integrated, intelligent system that includes information acquisition (retina and vestibular apparatus), motion control (cerebellum and brainstem), and signal processing (occipital lobe, superior colliculus, and other brain regions). It is also a representative example of what brain-inspired intelligence research is attempting to replicate. The Bionic Vision System Laboratory has succeeded in the step-by-step mathematical modeling and function simulation of the human visual system. Based on its experience of the physiological and physical characteristics of cerebellum cells, SIMIT constructed a mathematical model of a single cell and an equivalent circuit. This work was published in *Nature Precedings* in 2008 (*21*). In the paper, a neuron was considered as a signal processing unit. By analyzing the relationship between the input of a synapse and the currents across postsynaptic membranes, a dynamic pulse frequency model of a neuron could be obtained. Subsequently, the team has been researching brain-like chips. A brain-like chip architecture is a new type of microchip architecture that mimics the human brain. The processor is similar to a neuron, and the memory unit and communication system resemble a synapse and nerve fiber, respectively. The chip integrates neuronal information processing, synaptic information recording, and axon information transfer in almost the same manner as the human brain. Thus far, SIMIT has established the calculation functions of an equivalent circuit (a theoretical circuit that retains all electrical characteristics of a given circuit), involving the plus, minus, proportional, and integral functions for the pulse frequency, and has employed them to construct a practical motor neuron control system. The team analyzed how signals from the eye travel to the brain stem and impact control of the nervous system. After over 30 years of effort, researchers at SIMIT have come to understand the core theory of binocular vision control and have established mathematical models for control of human visual neurons and binocular vision. These models have been continuously improved and refined through practical engineering applications.

SIMIT has developed several bionic visual products and technologies thus far, including video capture, image processing, and video display. Focusing on the brain, which is the most biologically advanced center for signal processing, SIMIT has proposed a "Machine Consciousness Space" concept. The SIMIT team is intent on mapping the real world to the "consciousness space" of a machine, thus it has developed a series of core algorithms based on binocular vision, including algorithms for high-precision 3D reconstruction, visual odometry, visual saliency, road detection, target detection, and tracking, among others.

The bionic vision team at SIMIT has independently developed a bionic machine–brain system tailored to performing the functions of perception, interaction, analysis, and determination. This system is modeled on brain structure, complete with binocular vision hardware, intelligence processing, and control software corresponding to the functions of the cerebellum, midbrain, and brainstem, respectively. The proposed system demonstrates outstanding abilities including human-like visual perception and interaction, 3D reconstruction of the consciousness space, and cognition and determination in dynamic environments.

The bionic vision team at SIMIT owns extensive intellectual property in the field of bionic visual control systems. It has applied for 46 patents internationally, of which 25 have been granted, in countries including China, the United States, and Japan. The core vision technology system integrates diverse technologies including ophthalmology, robotics, artificial intelligence, and computer vision, demonstrating its complexity and pointing to the high level of basic research and expertise needed for its construction. This technology has been broadly commercialized, with applications in the fields of 3D photography, robotic vision, intelligent security, virtual reality, intelligent transportation, IoT, and smart health care, among others.



Mathematical model of a neuron (*21*)

Looking to the future, SIMIT will continue to explore the mysteries of brain-inspired intelligence and begin to more deeply analyze the structure of the cerebellum, including the principles of learning and adaption, with the aim of designing a new mathematical model of neural networks that can be implemented in future hardware devices. In addition, SIMIT plans to design an equivalent circuit and a chip-based binocular motion control model. Moreover, SIMIT will focus on developing a new and efficient multimodal information fusion model based on the information integration mechanism found in the brain, in order to build an advanced brain-inspired intelligence system that integrates vision, auditognosis, and tactus based on a visual-processing mechanism. By exploiting the resources of cloud computing platforms, the machine brain will be extended to a cloud brain with decision-making capacity, to promote development toward a cloud-based intelligence platform.

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Research platforms at SIMIT

In order to support existing research activities, SIMIT has established five major research platforms to meet the need for rapid development of materials investigation and characterization, device fabrication and integration, and system testing and verification. The platforms are summarized in the table and described in more detail below.

Platforms at SIMIT	Overview
8-in. "More-than-Moore" R&D Pilot Line	Over 5,000 m^2 of cleanroom space, more than 100 installed tools for wafer processing and packaging, and an established suite of micro/nano process flows. Forms an integral part of the microfabrication consortium and provides leading-edge integrated circuit (IC) capabilities in microelectromechanical systems (MEMS), silicon photonics, radio frequency (RF) communication, complementary metal-oxide semiconductor (CMOS) logic, silicon-based III–V power supplies, three-dimensional (3D) integration, tunneling magnetoresistance (TMR) magnetic sensing, and insulated-gate bipolar transistor (IGBT) back-end technologies.
Silicon-Based Photonics Technology Platform	Including standard wafer cleaning, ion implantation, diffusion and oxidation, silicon-germanium (SiGe) epitaxy, rapid thermal annealing of signal-to-distortion spikes, and metal/silicide for good contact, metallization, and dielectric [low-kappa (low-κ)] deposition; plasma etching for poly-Si and dielectrics; chemical-mechanical polishing; and inline metrology/analysis.
Shanghai Integrated Platform for Materials of Energy and Environment	The first synchrotron-based integrated research platform that combines molecular beam epitaxy (MBE)/oxide MBE (oMBE), angle-resolved photoemission spectroscopy (ARPES), scanning tunneling microscopy and spectroscopy (STM/STS), ambient-pressure photoemission spectroscopy (AP-PES), and ambient-pressure photon-in/photon-out spectroscopy (AP-PIPOS) techniques.
Superconducting ELectronics Facility (SELF)	One of the world's most advanced R&D platforms for superconducting electronic devices and circuits. Includes a 650-m^2 cleanroom facility (with a 150-m^2 class-100 section) and advanced micro-/nanofabrication equipment such as a multichamber magnetron sputtering system, high-vacuum evaporator, electron-beam lithography system, i-line stepper, mask aligner, coater/developer, reactive-ion etching system, X-ray diffractometer, atomic force microscope, and scanning electron microscope (SEM).
Microstructural Characterization Platform of Functional Materials for Informatics	Provides a series of characterization techniques ranging from microstructure and composition analysis and electrical performance analysis of materials to atomic and electronic structure analysis of materials. Includes double spherical aberration coefficient (Cs)-corrected transmission electron microscope (TEM), 3D atom probe, low-temperature/high magnetic field scanning microwave impedance microscope, focused ion beam SEM system, field emission TEM, and field emission SEM.

The 8-in. "More-than-Moore" R&D pilot production line

8-in. "More-than-Moore" R&D Pilot Line

Shanghai is a leading base for the semiconductor industry in China and home to many global enterprises in industries such as mobile phone and automobile manufacturers. It is therefore an ideal development environment for the global microelectromechanical systems (MEMS) industry, and a primary reason why the Shanghai Industrial μTechnology Research Institute (SITRI) was created by SIMIT. SITRI has taken the next step in driving the development of the MEMS industry by investing in the construction of an industry leading R&D pilot line for MEMS and other "More-than-Moore" (MtM) technologies.

The 8-in. MtM R&D pilot production line in Shanghai has over 5,000 m^2 of cleanroom space, more than 100 machines for wafer processing and packaging, and an established suite of micro/nano process flows. The line is compatible with the production capabilities of SIMIT's foundry partners, to ensure seamless transfer from R&D to high-volume production, particularly for MtM and 3D integration technologies. It is an integral part of the pilot manufacturing consortium and provides leading-edge IC capabilities in MEMS, silicon photonics, RF, CMOS logic, silicon-based III–V, 3D integration, TMR magnetic sensing, and IGBT back-end technologies.

This R&D pilot line enables SIMIT to support state-of-the-art research in advanced materials and sensor prototyping by working with its research and industry partners through an open R&D model to deliver commercially ready products to the market—products that are readily available to scale up to mass production. It is not only an important bridge between R&D and manufacturing, but also a crucial platform to enrich and improve the MtM ecosystem in China, and a key strategy to help domestic innovations gain a foothold in global markets.

Demonstrated SIMIT capabilities

Products

- Inertial sensors
- Environment sensors
- Acoustic sensors
- Microstructures
- Magnetic sensors
- TMR sensors
- Infrared radiation CMOS image sensor (IR-CIS)
- Actuators
- Power devices (RF, III–V)

Universal platforms

- Compatible with CMOS back-end-of-line
- Redistribution layer technology
- Through-silicon vias (vertical interconnect access) technology

Advantages

- Fast feedback and development cycle
- Customized and flexible process development
- Experienced technology team and consultants
- Intellectual property protection in both development and transfer
- Full analysis, testing, and characterization capabilities

Silicon-Based Photonics Technology Platform

In 2004, Intel released the first high-speed GHz silicon modulator developed using the CMOS platform, leading silicon-based photonics into a new era. Semiconductor giants including Intel and IBM, as well as top universities and institutes worldwide, played important roles in this technological breakthrough. High-performance devices including silicon electro-optical modulators, germanium-based high-speed optical detectors, low-loss silicon nanowire waveguides, tapered and grating couplers, wavelength division multiplexer components, and polarization-related devices, among others, have been made possible through advances in silicon usage, which has also enabled the production of large-scale integrated photonics circuits and optoelectronics integration. The potential of a silicon laser is still being researched because silicon is not a direct bandgap material (the bandgap is the range of energy levels within a given solid that are not possible for an electron to possess). Great strides have been made in this field through the use of hybrid bonding, quantum dot epitaxy, and bandgap engineering. Presently, driven by industrial applications such as data communications, telecommunications, autopiloting, and physical data collection (such as temperature), CMOS platforms are urgently needed for R&D into integrated silicon photonics chips. However, commercial CMOS fabrications cannot provide adequate support for silicon photonics due to process capability overload. Moreover, the Interuniversity Microelectronics Centre (IMEC) and A*STAR's Institute of Microelectronics (IME) are the only silicon photonics fabrication systems open to international users, and their availability is limited. Therefore, SIMIT initiated a 200-mm silicon photonics pilot production line in collaboration with the local government in Shanghai. This production system shares the front-end-of-line with the 200-mm MtM line. The back-end-of-line is dedicated to the silicon photonics process, in order to guarantee the quality of the fabrication by avoiding contamination with other materials and metals.

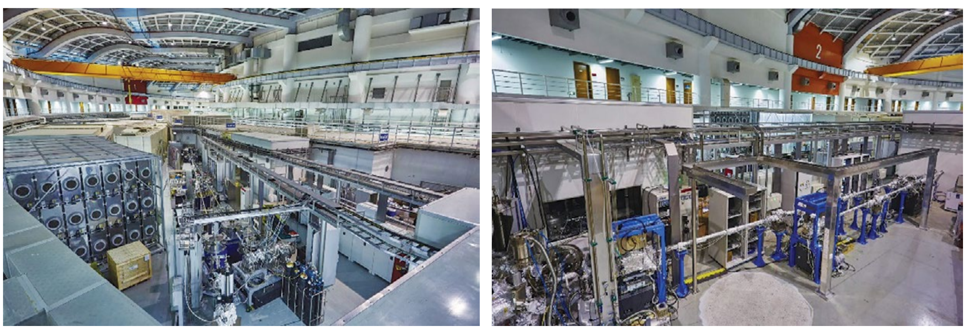
The silicon photonics pilot platform is targeted at R&D and small-volume production (~500 pieces/month) for the industry. The core process blocks include standard wafer cleaning, ion implantation, diffusion and oxidation, SiGe epitaxy, rapid thermal annealing for signal-to-distortion spikes, and metal/silicide for good contact, metallization, and dielectric (low-κ) deposition; plasma etching for poly-Si and dielectrics; chemical-mechanical polishing; and inline metrology/analysis. Equipped with 248-nm and 193-nm deep-ultraviolet photolithography systems, it can fabricate chips with a critical dimension of 90 nm, and has a passive and active device library, supporting silicon photonics products over 25 gigabits per second (Gbps) for the high-speed optical module at 100 Gbps and beyond. The platform provides a process design kit for standard fabrication and also supports customized process development. Typical products that the team can support include integrated chips for high-speed transceivers, light detection and ranging (LiDAR) devices, biosensing technologies, and integrated microwave photonics, along with fundamental research into photonic crystals, metamaterials, and plasmonics.

Multiproject wafer and customized process services are open to international customers, and these processes are available for transfer to mass production fabrications through further collaboration. 3D/2.5D optoelectronic interconnection is another important technology that is being developed on the platform, which offers China's most economical, high-performance solution for the interconnection of individually fabricated optical and electronic state-of-the-art parts. SIMIT/SITRI aims to build the first dedicated silicon photonics technology platform in China by combining advanced research, multiproject wafer services, training, and client product support.

The operations team has several years of experience in process development and technical collaboration with global silicon photonics companies, aiding them in moving their product from prototype to mass production. Furthermore, Shanghai Simgui Co., Ltd., another innovation partner and a spinoff of SIMIT, is equipped to supply customized silicon-on-insulator (SOI) wafers such as multilayered SOI and cavity SOI, thereby offering more flexibility in the design and fabrication of integrated photonics chips. An advanced silicon photonics project will be launched next year with the support of the Shanghai government, which aims to promote the city's optical communication industry by speeding up domestic production of integrated optoelectronic chips and building the silicon photonics industrial chain and ecosystem. The Shanghai municipal government is committed to building a world-class silicon photonics R&D base there, and the pilot production line is one of the most important parts of this project, together with the development of optoelectronics hybrid packaging, high-speed IC drivers, and high-performance integrated photonic chips.

Shanghai Integrated Platform for Materials of Energy and Environment (SiP.ME^2)

Traditional methods for studying the electronic structure of materials are restricted by the lack of progress in advanced light sources such as synchrotron radiation. The relatively homogenous information is inadequate to satisfy the needs of the rapidly developing field of modern energy and environmental materials science. SiP.ME^2 is the first synchrotron-based integrated research platform that combines molecular beam epitaxy (MBE)/oxide MBE (oMBE), angle-resolved photoemission spectroscopy (ARPES), scanning tunneling microscopy and spectroscopy (STM/STS), ambient-pressure photoemission spectroscopy (AP-PES), and ambient-pressure photon-in/photon-out spectroscopy (AP-PIPOS) techniques. Samples in this platform can be switched between these different measuring techniques with the aid



SiP.ME^2 beam lines and stations for in situ characterization of the electronic structure of energy and environmental materials

of the in situ or movable vacuum sample transfer device. Each part of the platform has an independent function and can handle the needs of independent research tasks. When integrated as a whole, the system's capability is significantly greater than that of each subsystem alone.

Through the latest MBE/laser MBE integrations, the growth of a material can be precisely controlled at the cell or even atomic level. The platform provides comprehensive control of all aspects of production, including the end face, surface, interface, composition, stoichiometry, structure distortion, and strain on the material, and can also enable the creation of artificial microstructures through a thermal nonequilibrium process. Therefore, not only does it circumvent restrictions encountered with traditional electronic structure research, but also shifts traditional ideas about materials research. We believe its operation will advance innovative, multidisciplinary materials design, fabrication, and characterization, significantly broadening the scope and capabilities of research into the structure of electronic materials.

The Superconducting Electronics Facility

The platform allows for in situ characterization at near-atmospheric pressure, enabling the study of the electronic structure of materials under different states, different atmospheres, and different loading conditions. For example, near-atmospheric pressure technology can measure the electronic structure of the sample surface in the presence of liquid water, which provides a novel method for application in water science, environmental science, corrosion protection, and other fields important to China. Near-atmospheric pressure is useful for analyzing in situ loading of materials and devices, and can simulate the running conditions of materials and devices. Therefore, the material surface can be measured under nonequilibrium conditions, and physical and chemical properties of materials can be accurately and reliably obtained. The platform can also provide scientific evidence for the control and improvement of new energy materials.

Incorporation of advanced light sources, including X-ray synchrotron radiation light sources, deep ultraviolet lasers, and subfemtosecond pulse light sources can significantly improve the platform's performance, overcoming the limitations of traditional ultrahigh vacuum ARPES measurement technology. It can enable the difference in electronic effect between surface and bulk materials to be distinguished, and promote the development of measurement technologies for interface electronic structure and ultrafast electron spectra.

The platform offers excellent complementarities for electronic structure measurements and analyses. Photoemission spectroscopy (PES) provides electronic structure information at the valence and core level, X-ray absorption spectroscopy (XAS) provides unoccupied state information, X-ray emission spectroscopy (XES) yields occupied state information, and the combination of ARPES and STS gives information about electron states with near-Fermi level accuracy. Thus, complete information on the electronic structure of materials can be obtained from this platform.

Utilizing the latest advances in controllable material growth, precise electronic state measurement, and advanced light sources, this platform is capable of in situ and/or in operando measurement of the electronic structure of materials with ultrahigh resolution, and has great potential for application in the fundamental and applied research of new energy and environmental materials.

Superconducting ELectronics Facility (SELF)

Since 2005, SIMIT began research on low-critical temperature (low-T_c) niobium (Nb)-based superconducting electronic devices and their applications in superconducting quantum interference devices (SQUIDs) and superconducting nanowire single-photon detectors (SNSPDs). It is well-known that device fabrication technology is one of the key issues facing superconducting electronics. It is critical to establish advanced comprehensive device fabrication facilities and develop basic technology for creating superconducting devices and circuits in China. Achieving this will significantly promote R&D of domestic superconducting electronic devices and subsequent cutting-edge applications in geological surveying, biomagnetic imaging, and quantum communication. For these reasons, the Chinese Academy of Sciences (CAS) began a support project in 2010 to establish a micro-/nanofabrication facility for superconducting devices and circuits, called the Superconducting ELectronics Facility (SELF). SELF aims to establish fabrication and characterization capabilities and develop process technologies with high reliability and stability for SQUID, SNPSD, transition-edge sensors, superconducting quantum bit (qubit), and single flux quantum (SFQ) superconducting devices and circuits, among others.

SELF is among the world's most advanced R&D platforms for superconducting electronic devices and circuits. A RMB

A selection of the equipment available within the Microstructural Characterization Platform of Functional Materials for Informatics. SEM, scanning electron microscope; 3DAP, three-dimensional atom probe; TEM, transmission electron microscope; Cs-TEM, spherical aberration coefficient TEM; FIB-SEM, focused ion beam SEM; sMIM, scanning microwave impedance microscope.

100 million (USD 15.8 million) investment has been committed for phase one of SELF, which includes a 650-m^2 cleanroom facility (with a 150-m^2 class-100 section) and advanced micro-/nanofabrication equipment such as a multichamber magnetron sputtering system (to fabricate Nb, Nb/AlOx/Nb, NbN, NbN/AlN/NbN, and NbTiN films), a high-vacuum evaporator, an electron beam lithography system (8-nm resolution and 9-nm overlay accuracy), an i-line stepper (0.35-μm resolution and 40-nm overlay accuracy), a mask aligner (2-μm resolution and 0.5-μm overlay accuracy), a coater/developer, a reactive-ion etching system, an X-ray diffractometer, an atomic force microscope, and a SEM. SELF can perform micro-, submicro-, and nanoscale patterning with high overlay accuracy as well as fabricate superconducting devices and circuits on 2-, 4-, and 6-in. substrates. Approximately RMB 70 million (USD 11 million) has been invested in phase two of SELF, which will add another 600-m^2 cleanroom as well as multiple pieces of advanced process equipment including a chemical-mechanical polisher, an ultrahigh vacuum (UHV) sputtering cluster, a UHV evaporation cluster, a plasma-enhanced chemical vapor deposition system, an ion-beam etching system, an inductively coupled plasma etching system, and a deep silicon etching system. After the construction of phase two, SELF will be a state-of-the-art platform for the fabrication of high-performance superconducting devices and large-scale integrated digital circuits. With support from SELF, SIMIT has successfully developed Nb- and NbN-based Josephson junctions, SQUIDs/nanoSQUIDs, and high-efficiency SNSPDs for a variety of applications.

SELF is an open, shared platform, available on a fee basis or for use in collaborative research projects by government, industry, and universities. We expect and encourage scientists worldwide to utilize SELF**.**

Microstructural Characterization Platform of Functional Materials for Informatics

With the increase in research into functional micro-/nanostructure materials for informatics, the new micro-/nanoscale characterization technology has grown in importance in materials research. The development of nanoscale detection and characterization technologies—used to observe the atomic and electronic structures of nanostructural materials and measure the force, electrical, light, and magnetic properties of various nanostructures—is an essential function of the Microstructural Characterization Platform of Functional Materials for Informatics. SIMIT established the platform more than a decade ago, and it now provides a series of characterization techniques ranging from microstructure and composition analysis to electrical performance analysis to atomic and electronic structure analysis. The platform can provide deep technical support for scientific research in many fields. It can simultaneously provide high-level testing and consulting services as well as training for research institutes, universities, and enterprises.

The platform focuses on solving important, basic scientific problems in the development and application of functional materials for informatics. It is equipped with a range of high-end equipment, including an 80-picometer ultrahigh-resolution double spherical aberration coefficient (Cs)-corrected TEM that can be used to observe atomic images at nanometer scale and perform a range of in situ experiments. The platform also boasts a 3D atom probe that can analyze the elemental makeup of complex structures, intuitively reconstruct the 3D distribution pattern of the different elements in nanometer space, and provide precise element space content. Other technology includes a low-temperature/high magnetic field scanning microwave impedance microscope, a focused ion beam–scanning electron microscope, a field emission TEM, and a field emission SEM.

Since the completion of the platform, it has been providing extensive technical support for scientific research in many areas, such as superconducting materials and electronics applications, advanced silicon-based materials and applications, novel nanoelectronic materials and devices, and compound semiconductor materials, devices, and applications. It has promoted the rapid development of world-class, original scientific research into functional materials for informatics.

"Three-in-One" Collaborative Innovation System

With the rapid development of China's economy, the Chinese Academy of Sciences (CAS) has adopted a guiding principle for a new area of pioneering research focused on the frontiers of science, national priorities, and economic development, and is committed to achieving breakthrough developments in science and technology (S&T). To promote economic progress and make significant contributions to the development of emerging industries, CAS initiated the knowledge innovation program Innovation 2020, which aims to further promote innovation and attempts to turn scientific discoveries into technologies that power economic growth and sustainable development.

During its 90 years of development, SIMIT has assumed a key role as a driver of national technological innovation and supporter of nationwide S&T development. SIMIT has defined its development strategy by emphasizing greater reliance on innovation to meet national strategic priorities. International collaboration helps SIMIT access global knowledge and innovation environments. Furthermore, SIMIT develops research from an international perspective. In July 2017, SIMIT was approved by the General Office of the State Council of the People's Republic of China as a "Demonstration Base of Mass Innovation and Entrepreneurship," to undertake the mission of continuous innovation and promote the development of entrepreneurship.

Establishment of the "Three-in-One" Collaborative Innovation System to improve the R&D ecosystem

Building upon SIMIT's years of experience in scientific research and industrialization, and to demonstrate its support for the Innovation 2020 initiative, the "Three-in-One" Collaborative Innovation System was established, with SIMIT as the center of advanced research, the Shanghai Industrial µTechnology Research Institute (SITRI) as the technology transfer and pilot platform, and SIMIC Holdings as the industrialization platform focused on capital operation.

SIMIT: Advanced research

SIMIT contains several state key laboratories and CAS key laboratories that provide strong R&D capabilities for basic S&T, while the Center for Excellence in Superconducting Electronics conducts research in strategic advanced technologies. In recent years, SIMIT has focused its research on materials and information S&T, to promote the technology transfer of new innovations from CAS. Additionally, the laboratories, in concert with the SIMIT platforms, are undertaking advanced research that improves the analysis of how emerging industries impact public welfare.

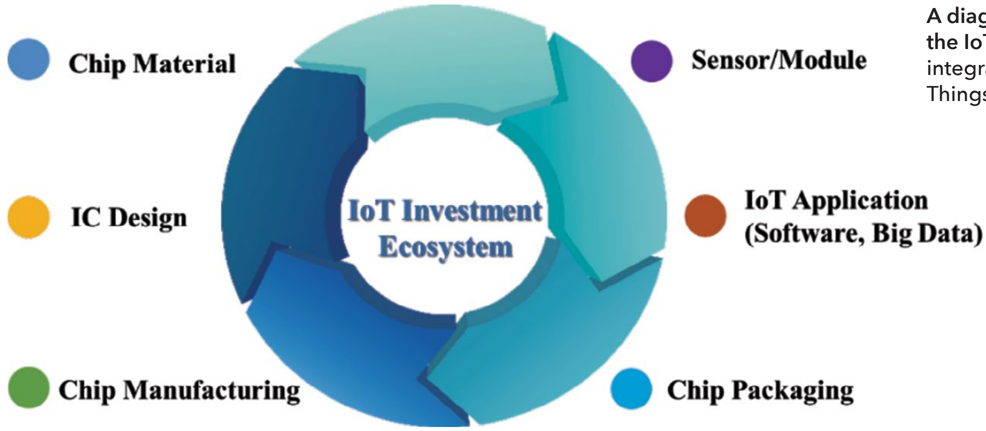
"Three-in-One" Collaborative Innovation System at SIMIT

SITRI: Accelerating technology development and commercialization

In 2013, SIMIT established SITRI, a new type of international innovation center committed to accelerating innovation and commercialization of "More-than-Moore" technologies to power the Internet of things (IoT). SITRI serves as the technology transfer and pilot platform for commercial partners and startups, and was approved by the State Council as the lead institute for the construction of the Shanghai Technology Innovation Center.

SIMIC Holdings: Leading industrialization

SIMIC Holdings Co., Ltd. is the industrialization and asset management platform of SIMIT. Thus far, SIMIC Holdings has invested over RMB 330 million (USD 52 million) in S&T programs, and has raised over RMB 20 billion (USD 3.1 billion) in outside investment to promote the industrialization of S&T innovations. SIMIC Holdings has established a successful business model consisting of technology R&D (SIMIC R&D), incubation (SIMIC incubator), venture capital (SIMIC capital), and an industrial cluster (SIMIC industry) to support the rapid development of innovative high-tech enterprises.



A diagrammatic representation of the IoT investment ecosystem. IC, integrated circuit; IoT, Internet of Things.

Three platforms supporting technological innovation

The carrier platforms

SIMIT has three campuses, in Changning, Jiading, and Xuhui districts, which have all assumed the role of incubator platforms to support the "Three-in-One" Collaborative Innovation System. SIMIC Holdings established the Shanghai IoT Center in the Jiading district, where the planned Sino-Finnish Innovation Science and Technology Industrial Park will be located, with the aim of creating an international innovation and entrepreneurship site. To meet the needs of the international R&D institutions and companies incubated in SIMIC Innospring (located in the Shanghai IoT Center), SIMIT created an advanced platform for intelligent sensor and IoT development as well as a professional incubator and makerspace for intelligent sensors and IoT at the Changning and Xuhui campuses, which are intended to provide professional services. Similar resources related to sensor and IoT technology will also be integrated in the "Three-in-One" Collaborative Innovation System.

The technology platforms

The establishment of open technology platforms for sensor, silicon photonic, and superconducting quantum communication has been supported through the "Three-in-One" Collaborative Innovation System, together with platforms for technology R&D and technology transfer, and the incubation of advanced R&D platforms. The development of the 8-in. "More-than-Moore" R&D pilot production line, superconductor production line, and 5G system platform have all contributed significantly to entrepreneurship and the emergence of new industries. Cooperation between the technology platforms and domestic research institutes, universities, and foreign research institutions has been strengthened, leading to the growth and increased capabilities of these platforms.

The funding platforms

The IoT Fund Ecosystem was established to support entrepreneurship among high-tech IoT enterprises at all stages of development. The system allows for complication-free investment in quality projects. It employs a collaborative process across the different stages of the funding process (see Figure 1), encouraging the support of quality projects while controlling investment costs. It also engenders improved social benefits and has seen superior economic returns.

Through the "Three-in-One" Collaborative Innovation System, the IoT Fund taps into the resources of the Yangtze River Delta, including technology, talent, and capital, to strengthen the fund ecosystem. By promoting rapid innovation in sensor technology, IoT, and information and communication technology, the IoT industry has made significant strides in recent years. Investing in enterprises at all stages of product development diversifies investment risk. The IoT Fund will act as a bridge to connect those enterprises in which SIMIT has invested with those supported by the fund as well as the fund's shareholders and partners. These connections will create synergies across the IoT ecosystem, covering upstream design, manufacture, packing, and testing of materials; midstream production of core components, sensors, modules, and network transmission devices; and downstream software application, data processing, problem solving, system integration, technology services, and software operation.

Replication of the "Three-in-One" innovation

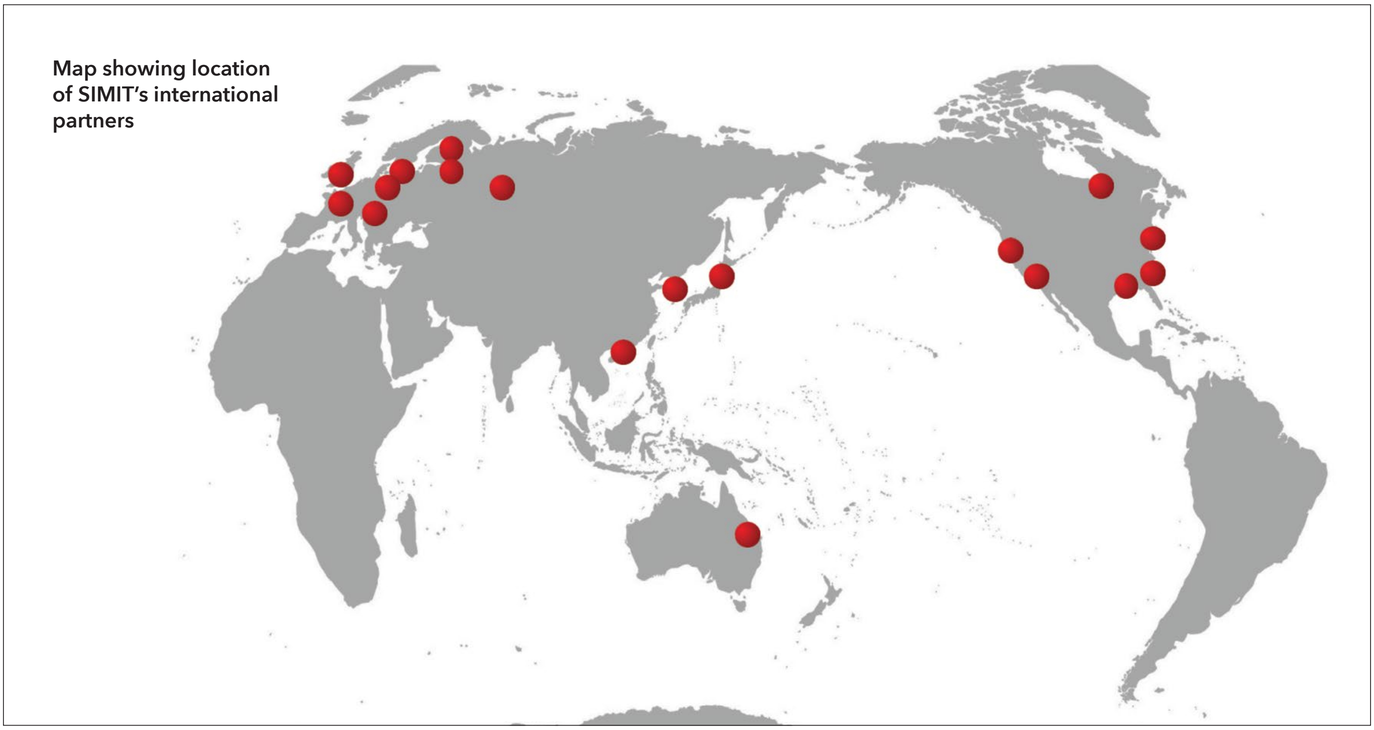
The Fuzhou IoT Open Laboratory (FIOT-LAB) was established jointly by SIMIT and the Fuzhou Municipal Government in April 2017, based on the "Three-in-One" Collaborative Innovation System. FIOT-LAB focuses on narrowband IoT (NB-IoT) technology R&D, which enables multiple IoT devices to be connected through cellular networks. Incubation of new industry startups is an important means to accelerate the growth of the IoT industry. FIOT-LAB emphasizes the integration of the IoT and semiconductor industries, and aims to become a national base for NB-IoT innovation.

With minimal effort, the "Three-in-One" Collaborative Innovation System could be replicated across China in cities like Chongqing and Nantong. SIMIT will continue to consider innovation as a formula for success as well as an effective means to advance science and drive R&D that can power economic expansion and sustainable development. Against the background of Shanghai as an innovation center with global influence, the system will play an important role in supporting innovation that contributes to China's economic and technological growth.

International cooperation

SIMIT is committed to establishing international cooperation with top universities and research centers worldwide. Their collaborations with Forschungszentrum Jülich GmbH (FZJ) in electronics and with VTT Technical Research Centre of Finland and the Finland National Bureau of Technical Innovation in information technology began over 10 years ago.

Map showing location of SIMIT's international partners



Forschungszentrum Jülich GmbH

SIMIT is proud of its long-standing collaboration with FZJ to advance the field of electronics. FZJ, an affiliate of the Helmholtz Association, was established in 1956. It has more than 5,700 researchers and a strong reputation for cutting-edge scientific research, particularly in information technology, neuroscience, and energy and the environment.

SIMIT's collaboration with FZJ began in 2006 and has included personnel exchanges and cooperation on various projects, including the establishment of joint laboratories on superconducting and bioelectronics in 2010, and on quantum materials in 2014. SIMIT and FJZ signed an agreement to engage in the joint construction of the "Sino-German Virtual Joint Institute on Functional Materials and Electronics" in 2015. SIMIT and FZJ have undertaken four international programs, published 47 papers, generated 20 meeting reports, applied for two patents (one of which was granted), and have had seven joint Ph.D. students (four of whom were hired as assistant professors by SIMIT). Furthermore, they alternatively held seven workshops that provided the Sino-German scientific researchers with an opportunity to present their findings. In 2013, ZHANG Yi from FZJ won the Shanghai International Science and Technology Cooperation Award, while in 2014, YU Yuehui from SIMIT won the Helmholtz International Fellow Award.

On October 20, 2016, a high-level delegation comprising the chairman of the Helmholtz Association, the director of FZJ, and heads of several research centers affiliated with the Helmholtz Association visited SIMIT. The two institutes signed an agreement for a third round of strategic cooperation, under which both parties determined that it was to their mutual benefit to continue their strategic cooperation in areas such as superconducting technology, sensor technology, bioelectronics, energy and the environment, and quantum information. This cooperation will include constructing joint research laboratories and the sharing of research facilities, organizing academic seminars, and the exchange of personnel.

Signing of the strategic cooperation agreement between the Helmholtz Association Forschungszentrum Jülich GmbH and SIMIT; (left) WANG Xi , director of SIMIT, and **(right)** Sebastian M. Schmidt, vice-chairman of Forschungszentrum Jülich GmbH.

Finland

Focusing on the development of the new generation of broadband wireless mobile communication, SIMIT has maintained an excellent cooperative relationship with several countries including Finland, the United Kingdom, Sweden, Canada, and Australia, as well as with enterprises, universities, and research institutions known for their expertise in communication technology. SIMIT has signed cooperation agreements and undertaken joint international science and technology projects sponsored by national ministries and local governments, which have paved the way for the development of sustainable international collaboration.

SIMIT has actively participated in international scientific and technological cooperation and exchange projects sponsored by many countries and regions. Under the guidance of the Chinese Ministry of Science and Technology and the Finnish Ministry of Economic Affairs and Employment, SIMIT (on behalf of China) signed a memorandum of understanding for the Finland-China Strategic ICT Alliance Cooperation. It also officially launched the China-Finland Information and Communications Technology (ICT) Alliance for Production, Teaching, and Research, which marked the formal establishment of intergovernmental cooperation between China and Finland in science and technology innovation. SIMIT has hosted and participated eight times in Sino-Finnish international conferences on ICT, and more than 1,000 experts have been invited to visit SIMIT. This cooperation promotes scientific and technological innovation and knowledge sharing between the two governments, and advances the formulation of domestic and international research and production standards used by industry leaders. It also achieves the goal of using technology as a driver of innovation, and allows for the development of key technologies for wireless mobile communication in China. Recently, SIMIT has been working with the VTT Technical Research Centre of Finland—a state-owned nonprofit research entity—and the Finland National Bureau of Technical Innovation, to promote the construction of the Sino-Finnish Innovation Science and Technology Industrial Park.

SIMIT has actively participated in international scientific and technological cooperation and exchange projects sponsored by many countries and regions.

YU Yuehui (left) from SIMIT receiving the Helmholtz International Fellow Award from Jürgen Mlynek, president of the Helmholtz Association

Some of the attendees at the China-Finland International Cooperation Workshop and kickoff meeting for the collaborative research projects on 5G networks

Research talent at SIMIT

As a national institute, SIMIT is committed to furthering the frontiers of science, advancing national needs, and supporting the domestic economy. To do this, it has built a highly qualified team by providing a clear career structure and ensuring that it constantly improves the work environment it offers.

In September 2009, the Chinese Academy of Sciences (CAS) launched the Talent Cultivation and Recruitment Program, a system-wide project aimed at increasing recruitment and developing talent in various fields, with the overall goal of creating greater adaptability to the constantly changing requirements for expertise in China. Through this program, which includes the national Thousand Talents Plan, the Shanghai Thousand Talents Plan, and the CAS Hundred Talents Program, SIMIT selects top-level scientists who demonstrate ambition, ability, and passion. It also focuses on attracting and sponsoring outstanding overseas scholars and international scientists who are active at the forefront of science and technology to visit or work at SIMIT.

At the end of 2017, SIMIT had a staff of 610, of whom 80 were from outside China. There were 37 high-level researchers, including seven winners of the National Thousand Talents Plan award, two winners of the National Thousand Young Talents Plan award, five winners of the Shanghai Thousand Talents Plan award, and 22 winners of the CAS Hundred Talents Program award.

WANG Xi
Academician of CAS, Materials Scientist

WANG Xi's research interests include electronic materials, novel integrated circuit (IC) processes, and wireless sensor networks. Wang has long engaged in research on the physical phenomenon of the interaction between ion beams and solids under load, and has applied his research findings to the development of silicon-on-insulator (SOI) products. Based on research by Wang, particularly on the physical and chemical processes of ion-implantation SOI synthesis, SIMIT has developed a series of key technologies for industrial production of SOI materials technology, and has established an R&D and production base of SOI materials.

Wang has published over 300 scientific papers and has presented at international scientific conferences. He has received several awards and prizes for his academic achievements including the first prize of the National Science and Technology Progress Award.

ZOU Schichang
Academician of CAS, Materials Scientist

ZOU Shichang engages in the systematic study of ion beam–solid interaction and the use of ion beams for the doping, synthesis, fabrication, and surface layer analysis of semiconductor materials and devices. In the 1990s, Zou was involved in the development of the semiconductor industry in mainland China, and participated in the establishment of several IC companies, including Shanghai Huahong Grace, Shanghai Simconix Electronics Co., Ltd., Toppan Photomasks, and Shanghai Ericsson Simtek Electronics Co., Ltd.

Zou has won 14 awards and prizes, including the first prize for the National Invention Award. He has published over 300 scientific papers and mentored over 30 Ph.D. students. Zou is also an honorary member of the International Conference on Ion Beam Modification of Materials Committee.

LI Aizhen
Foreign Associate of the U.S. National Academy of Sciences, Materials Scientist

LI Aizhen has been engaged in studying semiconductor materials for over 50 years. She founded the Laboratory of Molecular Beam Epitaxy Semiconductor Microstructure Materials and Devices of the Shanghai Institute of Metallurgy, and participated in the establishment of the State Key Laboratory of Functional Materials for Informatics in 1993. From 1958 to 1980, she studied materials science, engineering, and applications of the single-crystal, micron-scale group III–V heterostructure.

Since the 1980s, she has been studying atomic layer molecular beam epitaxy growth and interface control, and group III–V compound semiconductor quantum structure materials, particularly their characterization and application in high-speed electronic devices and detectors. More recently, she has focused her research on mid-infrared band introns and transition quantum-cascade lasers, interband transition multiquantum-well laser materials and devices, and has conducted related physics research.

Li has published 235 papers and three treatises, and has been granted 17 national patents for her inventions. She has won one National Invention Award, four National Scientific and Technological Progress Awards, eight Natural Science Awards at the provincial and ministerial levels, and first and second prizes in the CAS Scientific and Technological Progress Awards, as well as the Golden Bull Award from the Ministry of Science and Technology. She was honored as a Woman Pacesetter of the Nation, a National Urban Female Contribution Model of the Nation, and a Shanghai Model Worker. Other honors received include "National Outstanding Returning Overseas Chinese Academics, and Their Families," and "Advanced Returning Individual Overseas Chinese, and Their Families," as well as honors from the Overseas Chinese Affairs Office of the State Council and the All-China Federation of Returning Overseas Chinese. In addition, she was granted the honorable title of "Outstanding Contribution Teacher" by the CAS Graduate School in 2008, was elected as a foreign associate of the U.S. National Academy of Sciences in May 2007, and won the Third World Academy of Sciences (TWAS) Engineering Science Award in 2004.

High-level staff at SIMIT

WANG Zhen

WANG Zhen received his B.S. from Nanjing University, China, in 1978, and his M.S. and Ph.D. from Nagaoka University of Technology, Japan, in 1988 and 1991, respectively. From 1991 to 2013, he worked at the National Institute of Information and Communications Technology (NICT) in Japan, where he served as a senior researcher, group leader, and distinguished researcher. He led the Superconducting Electronics Group in NICT from 1993 to 2012, and was honored as a NICT life fellow in 2011. After Wang was appointed as a Thousand Talents Plan professor in 2010, he joined SIMIT in 2013, where he is currently leading the Division of Superconducting Devices and Circuits. He is also a professor at the University of CAS and ShanghaiTech University.

Wang has conducted research primarily on the fundamental technology and applications of superconducting electronics, particularly niobium nitride (NbN)-based superconducting films and Josephson junctions, superconductor–insulator–superconductor (SIS) mixers, superconducting nanowire single-photon detectors (SNSPDs), superconducting single flux quantum (SFQ) circuits, and superconducting quantum bit (qubit) devices. He developed epitaxial growth technology for the fabrication of single-crystal NbN films and NbN/aluminum nitride (AlN)/NbN Josephson tunnel junctions. He was the first to demonstrate a low-noise SIS mixer using NbN/AlN/NbN tunnel junctions, and applied the NbN SIS mixers to the submillimeter-wave telescope for astronomical observation in collaboration with SHI Sheng-Cai of Purple Mountain Observatory, CAS, in China. He also pioneered the development of a qubit using NbN/AlN/NbN junctions in collaboration with HAN Siyuan of the University of Kansas and Yoshihiko Nakamura of Tokyo University. Since 2005, Wang and the NICT research group have developed high-performance SNSPD devices using NbN thin films, and applied the SNSPD system in the Tokyo quantum key distribution (QKD) Network, a field demonstration of long-distance QKD.

Wang has published over 300 papers in peer-reviewed academic journals and written chapters in the *Handbook of Thin Films* and the *Handbook of Terahertz Technology*. He has served as a committee member for numerous conferences in the field and chaired the 2nd International Workshop on Superconducting Sensors and Detectors in 2014. He received an award from Japan's Ministry of Posts and Telecommunications in 2000, and from Japan's Ministry of Education, Culture, Sports, Science and Technology in 2011; he also received Japan's Superconducting Science and Technology Award in 2011.

WANG Shumin

WANG Shumin received his B.S. and M.S. in physics from Fudan University, China, in 1985 and 1988, respectively. He earned his Ph.D. from the Department of Physics at Gothenburg University in Sweden, in 1994. He joined Chalmers University of Technology, Sweden, in 1994, and was promoted to associate professor in 1999 and full professor in 2008. In 2013, he was appointed as a Thousand Talents Plan professor at SIMIT. He has also been a professor at ShanghaiTech University since 2013.

Wang is an expert on the epitaxial growth and physics of low-dimensional semiconductor heterostructures and nanostructures. His current research interests include dilute bismide materials and devices, integration of light-emitting materials with silicon, group III–V nanowires and quantum dots, and epitaxial growth of 2D materials. He is the editor of *Lattice Engineering: Technologies and Applications,* has written seven book chapters, published over 420 international journal and conference papers, and holds seven Chinese patents.

Wang has worked as a leader or a principal investigator for over 10 years in Sweden under the European Union's Seventh Framework Programme, as well as on several Chinese national projects. He has been officially invited to nominate outstanding candidates for the Japan Prize and the Nobel Prize in Physics. He was appointed as a management committee member for the European Cooperation in Science and Technology Actions MP0805 and MP1204, and as a foreign reviewer for the Engineering and Physical Sciences Research Council in the United Kingdom, the Agency for Science, Technology, and Research (A*STAR) in Singapore, and the Polish Science Foundation. He has served as a committee member for several international conferences including the 14th (2006), 18th (2014), and 19th (2016) International Conference on Molecular Beam Epitaxy, and the European Molecular Beam Epitaxy Workshop each year since 2011. He was the chair for the 7th International Workshop on Bismuth-Containing Semiconductors in 2016 and has been a senior member of the Institute of Electrical and Electronics Engineers (IEEE) since 2009.

LIU Zhi

LIU Zhi received his B.Sc. in geophysics/physics from Beijing University, and his M.S. in electrical engineering and doctorate in physics from Stanford University. Before joining the Lawrence Berkeley National Laboratory as a career staff scientist, he was a research associate at Stanford University and the Stanford Synchrotron Radiation Laboratory. He is currently a professor at SIMIT and vice dean of the School of Physical Science and Technology at ShanghaiTech University. Liu is a recipient of the National Thousand Talents Plan award. His research interest is surface and interface science, particularly phenomena at gas–solid and liquid–solid interfaces, synchrotron/free-electron laser–based in situ characterization techniques, and advanced instrumentation development. He has published over 200 papers in peer-reviewed academic journals.

ZHANG Xiaolin

ZHANG Xiaolin received his B.S. from the Department of Power Systems of Northeast China Institute of Electric Power Engineering in 1985, and his M.S. in engineering (1989) and D. Eng. (1995) from Yokohama National University in Japan, where he worked as a research associate from 1989 to 1992. After completing his D. Eng., he worked as an assistant professor at the Laboratory of Biomedical Engineering of Tokyo Medical and Dental University. In 2003 he was made an associate professor at the Tokyo Institute of Technology (TIT), and in 2012, he became a full professor at the TIT Precision and Intelligence Laboratory. He has been a Thousand Talents Plan professor at SIMIT since 2013, and director of the Bionic Vision System Laboratory there since 2015, where he is currently researching brain-inspired intelligent vision systems. He has authored or coauthored over 80 technical journal papers and conference proceedings, and has over 30 granted and pending patents in countries including China, Japan, and the United States.

LIU Zhengxin

LIU Zhengxin obtained his B.S. in 1989 from the Department of Optical Physics, Changchun University of Science and Technology (Changchun College of Optics and Fine Mechanics), China, and his M.S. and Ph.D. from the Department of Electronic and Information Engineering at Toyohashi University of Technology in Japan, in 1997 and 2000, respectively. He worked in Japan at System Engineering Consultants Co., Ltd., Tateyama Kagaku Industry Co., Ltd., and the National Institute of Advanced Industrial Science and Technology before being appointed as a Thousand Talents Plan professor at SIMIT in 2010. He has also been a professor at ShanghaiTech University since 2012.

Liu is an expert on solar cell materials and devices, renewable energy, and measurement technology for solar cells. His current research interests include high-efficiency crystalline silicon solar cells, the physics of heterojunction structures, and solar cell standardization. He has translated a book entitled *Solar Cells* from Japanese to Chinese, authored over 100 journal papers, and holds four Japanese patents and five Chinese patents.

Liu has worked as a lead investigator for several Japanese and Chinese national projects and has served as a committee member for several international conferences. He is vice-chairman of Technical Committee 82 of the International Electrotechnical Commission (IEC/TC82).

TAO Hu

TAO Hu received his Ph.D. in mechanical engineering from Boston University in 2010, winning the Best Dissertation Award. His research interests have primarily focused on terahertz metamaterials using micro-electromechanical systems technology. After graduating, Tao joined the Department of Biomedical Engineering at Tufts University as a postdoctoral associate, and later advanced to research assistant professor.

In 2014, he was appointed as a Thousand Young Talents Plan professor at SIMIT where his research focuses on green nanotechnology and micro/nanotechnology-enhanced novel electronic and photonic devices for biomedical applications. Tao has published over 50 papers in peer-reviewed scientific journals including *Science* (cover), *Nature, Nature Photonics* (cover), *Nature Nanotechnology* (cover), *Nature Communications, Proceedings of the National Academy of Sciences of the United States of America, Advanced Materials* (cover), *Small* (cover), and *Physical Review Letters*.

LU Yumin

LU Yumin received his B.S. in materials science and engineering from Fudan University, Shanghai, China in 1996, his M.S. in materials science and engineering from The Ohio State University, Columbus, Ohio in 2001, and his Ph.D. in electrical engineering from the University of Michigan at Ann Arbor in 2005.

Lu has been a Thousand Young Talents Plan professor at SIMIT since 2014. He also serves as vice president of radio frequency (RF) technology for Shanghai Industrial μTechnology Research Institute (SITRI), focusing on the development of high-performance RF front-end components and millimeter-wave integrated circuits. Before joining SIMIT/SITRI, he worked in the United States for NXP Semiconductors, Autoliv, and M/A-COM Technology Solutions.

International Scientists at SIMIT

PHOTO: (JOHN CLARKE) PEG SKORPINSKI

John Clarke

Superconducting quantum interference devices (SQUIDs) provide extremely sensitive measurements of magnetic flux or of any other physical quantity that can be converted to magnetic flux. One of the world's renowned SQUID pioneers, John Clarke from the University of California, Berkeley, agreed to ongoing cooperation with SIMIT on SQUIDs and their applications, with a current focus on ultralow field magnetic resonance imaging (ULFMRI). A major advantage of ULFMRI is that the longitudinal relaxation time generally depends on the type of tissue being imaged, allowing, for example, imaging of tumors without contrast agents. Another evolving application is the use of a multichannel SQUID system that combines ULFMRI with magnetoencephalography to enable simultaneous structural and functional imaging of the human brain. Clarke shares his knowledge and experience of SQUID design and the ULFMRI system with SIMIT researchers and students by visiting Shanghai regularly. In addition, two young scientists from SIMIT were trained in Clarke's group at Berkeley to perform ex vivo and in vivo brain imaging, with much success.

Makato Sato

Makoto Sato, Distinguished Professor of SIMIT, is professor emeritus of the Tokyo Institute of Technology (TIT), former director of the Precision and Intelligence Laboratory of TIT, and former chairman of the Virtual Reality Society of Japan. He has dedicated his career to researching pattern recognition, image processing, human–machine interfaces, virtual reality, and haptic interaction. In 1989, Sato was the first to develop the haptic display system known as SPIDAR (SPace Interface Device for Artificial Reality), which is based on force feedback. The system connects hand-operated devices to a haptic interaction system that gives a machine realistic tactile sensation. The system can provide the operator with an authentic touch response for true-to-life interactions in different virtual environments. Through cooperation with Sato, SIMIT has realized the fusion of bionic vision and touch in the fields of robot control and mixed reality, and has expanded the multimodal biomimetic senses of brain-inspired intelligence, also providing technical support for brain-inspired intelligence research at SIMIT.

ZHANG Yi

ZHANG Yi, a German professor who obtained his Ph.D. from Justus Liebig University in Germany, is engaged in researching SQUIDs and their applications at the Forschungszentrum Jülich GmbH in Germany, and is a leading international scientist in the SQUID field.

Since 2006, Zhang has helped SIMIT to develop its superconductivity program through cooperative research and personnel training, thus aiding it in establishing a leading, international position in the SQUID field. A fruitful cooperative relationship has led to a breakthrough in SQUID technology that has advanced the field internationally. Zhang directed the SIMIT team in its development of the first multichannel, low-temperature superconducting magnetometer in China, and its successful installation in the Shanghai Sixth People's Hospital and Xuhui District Central Hospital. Zhang has given seminars on scientific research cooperation, setting up joint laboratories, and establishing an international cooperation institute. In 2014, he won the Shanghai International Science and Technology Cooperation Award.

SIMIT Talent Cultivation and Recruitment Program

Eligibility criteria

(candidates should fulfill any one of the following)

- Meet the requirements for Innovative Talents within the Thousand Talents Plan, or of Young Professionals within the Thousand Talents Plan;
- Meet the requirements of the Shanghai Thousand Talents Plan;
- Meet the requirements of the CAS Hundred Talents Program;
- Should be outstanding young and middle-aged scholars, doctors, and postdoctoral students from well-known foreign universities and research institutes.

Areas of research interest

- Intelligent sensing microsystems
- Superconducting quantum devices and circuits
- Advanced silicon-based materials and applications
- Special broadband wireless communication technologies and equipment
- Micro- and nanotechnologies for sensors and transducers
- Phase-change random access memory and applications
- Terahertz solid-state technologies
- Brain-inspired chips and bionic vision

Support and benefits

- The institute will fully support and assist candidates who meet the requirements of national talent projects such as the Thousand Talents Plan, the Shanghai Thousand Talents Plan, and the Hundred Talents Program of CAS.
- In accordance with the official provisions stipulated by SIMIT, Shanghai Municipality, and the Chinese government, the project candidates will receive a research and living allowance.
- The institute will offer a competitive salary and benefits, including social insurance, a housing fund, housing subsidies, and assistance to apply for permanent residence in Shanghai for project candidates, their spouses, and their children, in accordance with official policy.
- Temporary residences, necessary offices, laboratory rooms, and financial support will be provided for selected candidates.

Contact Information:

Please email your resume to lihua@mail.sim.ac.cn, or call +86-21-62511070-5701 if you are interested in applying.

For more information about SIMIT, please go to www.sim.cas.cn/rczpw

National Silicon Industry Group (NSIG)—the only officially sanctioned materials group in China—was formed in December 2015 and is headquartered in Shanghai. NSIG is the sole shareholder of Okmetic (producing wafers 200 mm in diameter and smaller), and the largest shareholder of Simgui, Soitec (manufacturer of silicon-on-insulator (SOI) substrates), and ZingSemi (300 mm diameter wafer producer). The shareholders of NSIG are Sino IC Capital, Shanghai Guosheng Group, SummitView Capital, SIMIC (the investment platform of SIMIT), and Shanghia Jiading Industrial Zone. The goal of NSIG is to enhance its leading position in the silicon materials industry and to be an internationally competitive platform.

NSIG

National Silicon Industry Group

300 mm wafers

- **ZingSemi**
  The first 300 mm silicon wafer producer in China, focused on 300 mm wafer production technology bottlenecks.

SOI wafers

- **Soitec**
  The world's largest SOI wafer supplier.
- **Simgui**
  Focused on the SOI market; expanding through construction of state-of-the-art SOI production line.

Customized wafers

- **Okmetic**
  The world's leading MEMS silicon/SOI supplier, focused on customized, value-added wafer products, including 200 mm wafer production.

ZINGSEMI

www.zingsemi.com

ZingSemi is a 300 mm semiconductor wafer manufacturer located in Shanghai and a part of the NSIG family. It produces 300 mm epitaxial and polished wafers, aiming to generate over 600,000 wafers per month.

SIMGUI

www.simgui.com.cn

Simgui is the largest epitaxial wafer provider in China, producing 150 mm-200 mm epitaxial and SOI wafers. It is the only company in the world with a full range of SOI technology including SIMOX, Bongding, SIMBOND™, and Soitec Smart Cut™.

OKMETIC

www.okmetic.com

Okmetic is the world's leading supplier of sensor wafers for microelectromechanical systems (MEMS) manufacturing, producing 150 mm-200 mm bonded SOI, cavity SOI, and double-sided polished wafers as well as specialized silicon wafers.

中国科学院上海微系统与信息技术研究所

SHANGHAI INSTITUTE OF MICROSYSTEM AND INFORMATION TECHNOLOGY, CHINESE ACADEMY OF SCIENCES

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