Strengthening Modern Electronics Industry Through the National Program for Intelligent Electronics in Taiwan

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ABSTRACT Taiwan's semiconductor industry has had a profound influence on both domestic economics and the global IT industry. To enhance its competitiveness and expand its global impact, the Taiwan government commenced the National Program for Intelligent Electronics (NPIE) in 2011 to promote technological innovation of medical electronics, green electronics, vehicular (car) electronics, conventional computer, communication, and consumer electronics, the so-called "MG+4C" applications. The government allocated a budget of $430 million over 5 years to facilitate technology development, advanced research, talent cultivation, industry promotion, and international collaboration. By coordinating with government agencies, research institutions, universities, and corporations, the NPIE develops an integrated framework of academia and industry in Taiwan. It also emphasizes the enhancement of product verification, regulations, and participation in international alliances and standards. By transferring academic results to industry in emerging MG+4C applications, it is expected that the NPIE will contribute to the global semiconductor community, energize Taiwan's IC industry, and create innovative products and intelligent systems for better life and better environment.

INDEX TERMS Electronics industry, integrated circuit technology, system-on-a-chip, medical electronics, power electronics, automotive electronics, three-dimensional integrated circuits, low power electronics.

I. INTRODUCTION

The global semiconductor market showed slow growth in year 2012 mainly due to decremented shipment of personal computers. Taiwan has the world's largest supply chains of integrated circuit (IC) industry and thus is also impacted by the global recession. According to the Market Intelligence and Consulting Institute (MIC) of the Institute for Information Industry (III), the IC industry revenues of Taiwan, including design, manufacturing, packaging, and testing, reached US$52 billion in 2012 [1], showing marginal growth over 2011 (Fig. 1).

Taiwan's IC industry began in the late 1970s with governmental initiatives to develop personal computer market. It is unique in efficient segmentation consisting of IC design, manufacturing, packaging, and testing (Fig. 2). The competitiveness of this industry also stems from the cluster effect of spatial proximity, particularly in the Hsinchu Science Park. However the trend of software/hardware integration, the slow-down of global economy, and the emerging competitors together post numerous challenges for Taiwan's semiconductor industry.

In the past, Taiwan's IC industry has profited from hardware manufacturing; however, the value of ICT ecosystem has shifted from hardware to software/hardware integration. Taiwan's first challenge is in lack of experience in software development, system-level integration, and services related to user experience. The second challenge is that most of Taiwan's enterprises are of small- and medium-scale, and

FIGURE 1. The IC industry revenue of Taiwan (Source: MIC, March 2013).
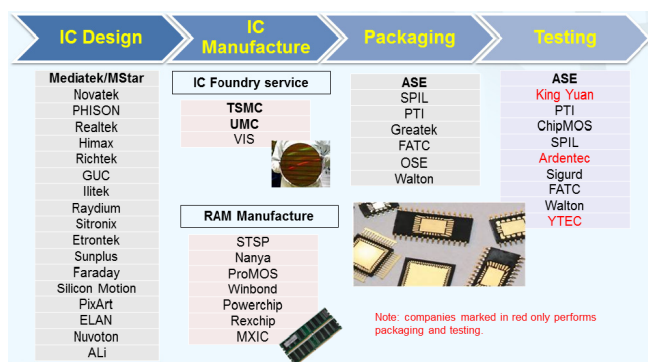

FIGURE 2. The vertically disintegrated framework of Taiwan's IC industry.

haven't held key components and intellectual properties (IPs). Finally, Taiwan's companies are less experienced at branding and global marketing and thus are easily marginalized when brand companies master the supply chain.

To address the aforementioned challenges, Taiwan government called a Strategic Review for the Semiconductor and IC Industry in 2009. Based on the conclusions, the ministry-level National Science Council (NSC) commenced the National Program for Intelligent Electronics (NPIE) with the mission of fostering Taiwan's IC industry for high-value applications. There are similar national efforts in the United States, European Union, Japan, Korea, and China. In the United States, the Semiconductor Research Corporation (SRC) runs programs for the design aspect in integrated circuit, device, system science, as well as cross-disciplinary semiconductor research [2]. There are also research programs in photovoltaic technology, energy storage, power electronics, and smart grids. In Europe, the HORIZON 2020 framework emphasizes on ICT technologies involving healthier lives, green economics, and safer and better society. Taiwan has been chosen as one of the top 20 international partners for collaboration on IC manufacturing technologies, nano-electronics, robotics, and e-health systems [3].

In Asia, Korea government chartered the National Science & Technology Commission (NSTC) in 2011 to draw the National Science & Technology Basic Plan, which emphasizes innovative nano-scale devices, smart IT convergence platforms, and multi-dimensional smart sensor systems [4]. In Japan, the science and technology policy is administered in a planned manner with dual guidelines of "S&T to be supported by the public; returning benefits to society," and "emphasis on fostering human resources

and competitive research environments; shift of emphasis from hard to soft resources; greater significance of individuals at institutions." [5] Currently, dependability and low energy are the major focuses of electronics related programs in Japan, such as the dependable wireless solid-state drive (SSD) project and the extremely low-power (ELP) project. In China, the government organized a national program from 2006 to 2020 for developing high-end general chips, basic software and electronic device [6]. There are also programs for super large-scale IC manufacturing technologies. Moreover, a long-term industrial plan (from 2011 to 2020) is conducted to promote the development of alternative energy and energy-efficient vehicles.

II. THE NATIONAL PROGRAM FOR INTELLIGENT ELECTRONICS OF TAIWAN

Taiwan's National Program for Intelligent Electronics (NPIE) will run for 5 years, from 2011 to 2015. It aims to develop technologies for emerging applications of *Medical* electronics, *Green* electronics, vehicular (*Car*) electronics, and conventional *3C* electronics, the so-called "MG+4C." The NPIE's ultimate goal is to strengthen Taiwan's IC industry and its value in the global ICT ecosystem.

From governmental perspective, the NPIE coordinates correlative projects and resources from government agencies, including the NSC, the Ministry of Economic Affairs (MOEA), and the Ministry of Education (MOE). From technical perspective, the NPIE's top-down strategy leads academia, research institutions, and industry toward technology development in the MG+C4C applications. From human resource perspective, the NPIE promotes cross-domain programs in universities to cultivate interdisciplinary talents for the growing industry. From industrial perspective, the NPIE improves the infrastructure to attract investment in high-value MG+4C sectors.

The NPIE's budget is allocated to development of key technologies and devices, advance of academic research, cultivation of interdisciplinary talents, and promotion and funding for innovative industrial R&D. For these purposes, the NPIE includes 7 subprograms: Medical Electronics, Green Electronics, 4C Electronics, Advanced Research, Talent Cultivation, Industry Promotion, and MG+4C Vertical Integration (Fig. 3).

After two years of its execution, the NPIE has achieved valuable outcomes in each of the M, G, and 4C fields. Notable achievements include the world's first solar-powered artificial retina, the fastest mega-bits nonvolatile memory, and the first experimental study of 60-GHz millimeter-wave life detection system. In addition, Taiwan's first 3D X-ray coherence tomography device for dental medication and the first 3D stacked memory are also demonstrated. Moreover, the NPIE has initiated a Silicon Carbide (SiC) industry, formed industrial alliances of medical-, green-, and 3D IC-related companies, incubated startups in MG+4C sectors, made outstanding achievements in academia, and won awards in prestigious international competitions.
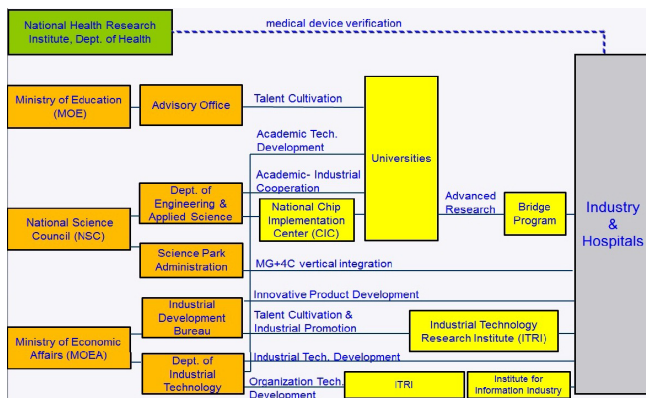
FIGURE 3. The NPIE's 7 subprograms.

FIGURE 4. The NPIE's executive framework.

III. NPIE EXECUTIVE FRAMEWORK

Depicted in Fig. 4, the NPIE's executive framework involves the Department of Engineering and Applied Sciences of the NSC, the Hsinchu Science Park Administration, the Department of Industrial Technology (DoIT) and the Industrial Development Bureau (IDB) of the MOEA, the Advisory Office of the MOE, the Industrial Technology Research Institute (ITRI), the National Chip Implementation Center (CIC) of the National Applied Research Laboratories (NARL), the Institute for Information Industry (III), universities, and corporations. These institutions collaborate on one or more of the 7 subprograms toward the ultimate goal of the NPIE.

A. MEDICAL ELECTRONICS SUBPROGRAM

The Medical Electronics Subprogram is designed to establish a highly competitive and vertically integrated supply chain for the medical electronics industry. The DoIT, the ITRI's Biomedical Technology and Device Research Laboratories (BDL) and Electronics and Optoelectronics Research Laboratories (EOL) carry out this subprogram. It has produced high-quality, cost-effective, advanced medical devices and provided common bio-signal platforms for portable medical electronics products. Take the optical coherence tomography (OCT) products for example, current worldwide specification has scanning speed at around 27 KHz and precision of 5–7 μm [7], [8]. One of the targets of this subprogram is to reduce the cost of OCT modules down to one-fifth to popularize the use in outpatient departments (OPDs).

B. GREEN ELECTRONICS SUBPROGRAM

The Green Electronics Subprogram develops high-value green ICs for the worldwide market. The executive organizations include the DoIT, the Information and Communications Research Laboratories (ICL) of ITRI, the Metal Industries Research & Development Center (MIRDC), and the Chung-Shan Institute of Science and Technology. This subprogram focuses on two types of products: photovoltaic (PV) and vehicular electronics. For PV electronics, it has developed micro-inverters, micro-converter regulators, driver ICs, power devices, and modules for Taiwan's solar power industry. For vehicular electronics, it focuses on battery management systems, automotive-grade high-power high-voltage devices, and high-efficiency heat recycling technologies. For the example of high-voltage (HV) power device, the world-leading Schottky diode product can operate at 1700 V. Since there is currently no such HV industry in Taiwan, one of the objectives of this subprogram is to create self-sustainable HV industry and its supply chain.

C. 4C ELECTRONICS SUBPROGRAM

The 4C Electronics Subprogram emphasizes advanced vehicular and novel 3C electronics through high-performance 3D-IC design and manufacturing technologies. This subprogram, involving the DoIT and the ICL, focuses on advanced 4C electronics systems, 3D-IC core technologies, 3D-IC design and verification platforms, and advanced circuit designs. This subprogram has developed intelligent power management technology, 3D-IC manufacturing processes, design services, and silicon intellectual properties (SIPs) for system-level integration. It has also developed advanced mixed-signal and ultra-low-voltage, ultra-low-power (ULP) circuit techniques for ubiquitous intelligent electronics systems. For the example of 3D logic/memory integration, this subprogram targets beyond the world's latest result, showing the number of TSVs (through silicon via), data bandwidth, and I/O power efficiency to be 14 654, 800 Gbps [9], and 0.11 mW/Gb/s [10], respectively.

D. ADVANCED RESEARCH SUBPROGRAM

The Advanced Research Subprogram focuses on promoting academic research and academia-industry collaboration. It is carried out by the Department of Engineering and Applied Sciences of the NSC and the CIC. Academic research projects explore advanced system-on-chip (SoC) design technologies for medical, green, vehicular, and 3C electronics. This subprogram also develops advanced design methodologies and platforms to accelerate the MG+4C product development. Furthermore, the NPIE Bridge Program facilitates the interaction between industry and academia, assists in technology mining and transfers, streamlines incubation services, accelerates the time to market for intelligent electronics, and promotes international cooperation to increase the industrial impact and global visibility of academic research results.

E. TALENT CULTIVATION SUBPROGRAM

The Talent Cultivation Subprogram fosters high-quality interdisciplinary talents for Taiwan's IC industry. It involves universities under the MOE and the Intelligent Electronics Institute executed by the IDB and the III. Its goal is to cultivate experts with innovation capabilities rooted in fundamental knowledge, talents with intelligent electronic systems and interdisciplinary integration capabilities, and managers with global views and competitiveness.

F. INDUSTRY PROMOTION SUBPROGRAM

The Industry Promotion Subprogram builds an industry-friendly environment to facilitate the development of advanced MG+4C products. The IDB is responsible for this subprogram. It improves the investment environment, promotes international participation, establishes industrial consortiums, and attracts overseas investment. It also collaborates with industry, research institutions, and government to define industrial standards and to accelerate the commercialization of innovative products.

G. MG+4C VERTICAL INTEGRATION PROJECT

The MG+4C Vertical Integration Project provides a collaboration model for companies in supply chain to develop novel electronics with integrated sensing capabilities such as sound, optics, heat, flow, medicine, and chemistry. The Hsinchu Science Park Administration is responsible for executing this project. It establishes standards for CMOS-MEMS sensor design, and utilizes Taiwan's excellent manufacturing capability. It also develops integrated design and production processes for innovative hybrid products and enhances cost-effectiveness and efficiency of the product supply chain.

IV. NPIE STRATEGIES

As shown in Fig. 5, the NPIE employs a three-tier strategy consisting of advanced research and talent cultivation in the upstream, development of core technologies in the midstream, and product development and industrial promotion in the downstream.

A. NSC AND MOE IN THE UPSTREAM

The upstream portion of the NPIE cultivates interdisciplinary talents capable of heterogeneous system integration. Anticipating the human resource needs in emerging MG+4C areas, the NPIE guides research and teaching in universities toward specific domains. Through the interflow of electronics engineering, computer science, biomedical engineering, industrial design, and practical experiments, students with cross-domain problem-solving capabilities will facilitate the development of MG+4C industry.

B. MOEA, ITRI, AND BRIDGE PROGRAM IN THE MIDSTREAM

The midstream portion of the NPIE seeks for breakthroughs in core industrial technologies of IC design and manufacturing. The NPIE Bridge Program collects the achievements
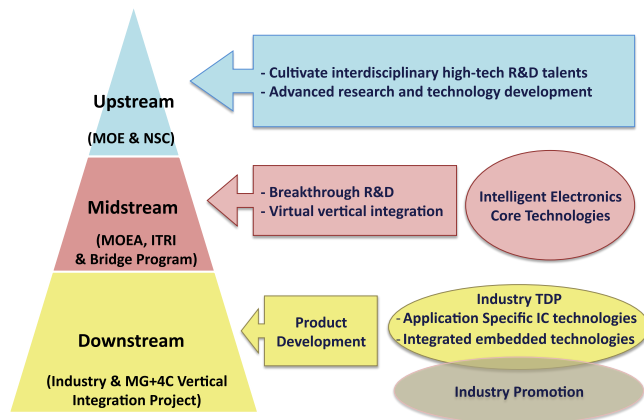

FIGURE 5. The NPIE's three-tier strategy.

produced from the upstream and transfers them to industrial use. This tripartite of academia, R&D organizations, and industry forms a benign circulation in which advanced research results are transformed into high-value products, and their royalty income, fosters the steady growth of emerging MG+4C market.

C. INDUSTRIES AND VERTICAL INTEGRATION PROJECT IN THE DOWNSTREAM

The downstream portion of the NPIE encourages and supports industrial R&D of MG+4C products and systems through technology development programs (TDPs) with governmental funding. It also promotes alliances in each of the MG+4C domains to strengthen the involvement in international standards. In addition, it supports industrial collaboration through the MG+4C Vertical Integration Project to enhance connections in supply chain and simplify product standardization process.

To raise awareness of world-wide MG+4C development, the NPIE supports international communication and collaboration. It encourages international joint R&D projects, visiting scholars and experts, international internship, and joint workshops and conferences. The CIC's advanced Multi-Purpose Wafer (MPW) shuttle service is open to international joint projects under the NPIE. It also serves as contact point between Taiwan's top research teams (35 teams from 19 universities) and international universities and research institutions. The NPIE constantly visits international institutions and enterprises to explore collaboration opportunity. Fig. 6 shows the international collaboration model of the NPIE.

V. NPIE CURRENT PROGRESS

Starting in 2011, the NPIE allocated approximately half of its budget to develop industrial technologies in medical, green, and 4C areas. After 2 years of program execution, the 7 subprograms of the NPIE have achieved valuable outcomes. In the NSC annual review and examination of national programs, the NPIE ranked first among the four economic-oriented national programs in Taiwan in terms of industrial
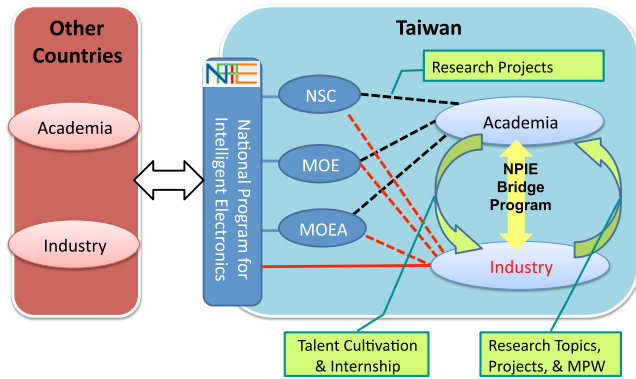
FIGURE 6. The NPIE's international collaboration model.

impact. The investment encouraged through the NPIE in R&D and manufacturing has exceeded US$21 billion in the past 2 years. The following paragraphs present the target technologies of the NPIE, and their effects on academia, industry, and society.

In the medical electronics development, the NPIE focuses on common bio-signal platforms and cost-effective, high-end medical systems. Modular OCT engines and portable ultrasounds have been developed and verified. The current result of our OCT module reaches scanning speed and resolution twice better than global leading products. Taiwan's first low-radiation 3D X-ray coherence tomography for dental applications (Fig. 7(a)) has also been prototyped and is currently under the supervision of institutional review board (IRB) for testing in local hospitals. The first reported experimental study of 60-GHz millimeter-wave life detection system (MLDS) for contactless human vital-signal monitoring (Fig. 7(b)) was also conducted [11]. Compact camera testing module for artificial retina is also world-leading in its testing space shrinkage, which has been significantly reduced to 1/10 with comparison to conventional products [12]. An 8-channel closed-loop neural-prosthetic SoC (Fig. 7(c)) with wireless power supply was implemented, and it detects more than 92% of seizures within 0.8 s [13]. A multiple-walled carbon nanotube-polymer composite sensor array was also proposed [14]. Its application on pneumonia identification won the Taiwan National Innovation Award in 2012.

In the green electronics development, the NPIE emphasizes automotive-specific ICs for import substitution and promotes Taiwan's autonomous green industry. The first AEC-Q100 qualified micro-controller (MCU) for motors in Taiwan and high-quality micro PV inverters have been developed. The industry chain from SiC bulk wafer, epitaxial, device design, manufacturing, to packaging, testing, module verification, has been developed. A 1200 V/450 A Si Insulated Gate Bipolar Transistor (IGBT) and SiC diode module (Fig. 8(a)) has been prototyped and tested in electric vehicles. Energy-efficient, self-recycling burn-in testing system has attracted industrial investment and key technologies including phase-shifted full-bridge series resonant DC/DC converters [15] and interleaved modular photovoltaic charger [16] have been

developed. Selected achievements in the green area under the NPIE are shown in Fig. 8.

In the 4C electronics development, the NPIE targets on core technologies for high-end mobile smart devices, including TSV-based 3D die-stacked IC, ULP technologies, and 3D nonvolatile memory (NVM) cubes. Taiwan's first fully-functional TSV-based 3D memory [17] and a face-to-face stacked CMOS image sensor (CIS) (Fig. 9(a)) have been demonstrated. The 3D IC Die Access Controller technical specification was also proposed to the IEEE SA P1838 (3D IC Test Working Group). The world's fastest (7.2 ns) random read/write mega-bit Resistive RAM (ReRAM) (Fig. 9(b)) was presented [18]. It has been transferred to Taiwan's DRAM companies for production of next-generation memory. Moreover, an on-chip AHB (advanced microcontroller bus architecture high-performance bus) bus tracer for versatile SoC debugging and monitoring was proposed [19]. Its application on the 3D graphics SoC won the Idea Erfinder-und Neuheiten-Ausstellung (iENA) Award in 2011. A low-power visual sensing node, working at 0.48 V with 0.57 nJ/pixel power consumption for video recording, was also presented [20]. It is the first solar-powered ultra-low-voltage (ULV) H.264 video-recording SoC (Fig. 9(c)) in the world.

In addition to the aforementioned achievements in industrial technology and academic research, the NPIE has also established alliances and special interest groups (SIGs) to highlight cooperation between academia and industry and to encourage investment in emerging MG+4C domains. Seven consortiums have been established, including the Digital Radiography Industry Alliance [21], the Medical Electronics SIG [22], the Vehicle Electronics SIG [23], the Wide Band Gap Power Electronics Consortium [24], and the Advanced Stacked-System and Application Consortium (Ad-STAC) [25]. Thirteen foreign and 85 domestic companies/organizations have joined these alliances. Furthermore, there have been 3 foreign companies building their research or business centers in Taiwan via the NPIE. These companies maintain close communication with the NPIE and related alliances. Finally, entrepreneurship encouragement and incubation service provided by the NPIE have successfully derived three startup companies, two in medical area and one in green area.

The NPIE has also produced global outstanding academic achievements. Over 600 international journal articles and 1000 international conference papers have been published in the past 2 years. Beyond the excellence of research teams, the NPIE has established world-leading IC design platform and shuttle service in the CIC. It currently provides 12 processes, including nanometer CMOS processes, CMOS MEMS, and CMOS BioMEMS, and has produced over 1,300 chips for academic teams in the past 2 years. To cope with the targeting fields of MG+4C, the integrated talent cultivation project under the MOE has also proposed innovative teaching programs that cover core IC design and cross-domain applications. Emerging topics on sensing, multi-core processor, 3D
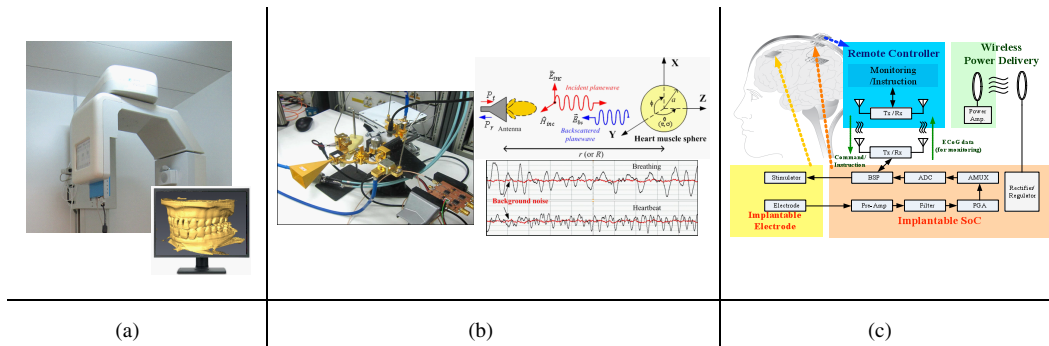
FIGURE 7. Selected achievements in medical electronics and systems. (a) 3D X-ray coherence tomography for dental application; (b) 60-GHz millimeter-wave life detection system; and (c) Closed-loop epileptic seizure detector.
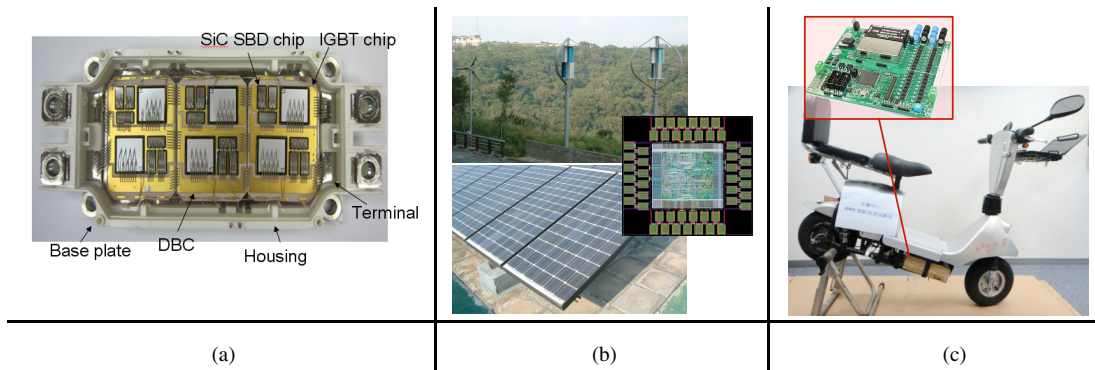

FIGURE 8. Selected achievements in green electronics and systems. (a) 660 V/450 A IGBT + SiC Schottky barrier diode; (b) Solar/wind dual-mode maximum power point tracking SoC; (c) The battery management system FPGA on electric scooter.
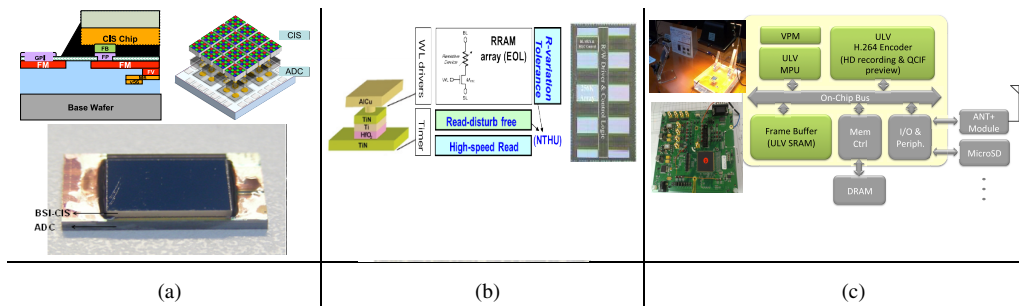

FIGURE 9. Selected achievements in 4C electronics and systems. (a) The world's fastest mega-bit nonvolatile memory; (b) Chip stacking of CMOS image sensor and analog-digital converter; and (c) Ultra low voltage video recording SoC.

IC and mixed-signal design have been integrated. Academic teams from Taiwan have proven their excellence in major international IC design and CAD competitions. Taiwan's brilliant human resource has benefitted to international joint programs and research centers, creating a win-win result.

VI. NPIE VISION AND FUTURE PLANNING
The NPIE is in a position to lead research and development on intelligent electronics for Taiwan's academia and industry, and to further benefit society with smart devices and intelligent systems. Based on Taiwan's existing global competitiveness, the NPIE is devoted to maintaining the leading position of Taiwan's IC industry through emerging MG+4C application domains. Coping with the practical needs of hospitals, the NPIE has developed cost-effective medical devices to popularize early stage diagnosis, improve health management, and

reduce expenses in the national medical system. By gradually building Taiwan's autonomous green and automotive industry ecosystem, the NPIE is moving Taiwan toward a low-carbon island with a sustainable lifestyle. By focusing on advanced IC technologies that emphasize minimization, mobilization, personalization, and energy efficiency, the NPIE expects to help Taiwan's IC industry maintain its share of the global market of intelligent electronics in the coming decades. Finally, by linking academic results and skilled talents to the industry and connecting Taiwan to international standardization communities, the NPIE is boosting startups and spinoffs toward the blue-ocean market of MG+4C.

In response to the rapid changes in global industry and market, and to instantly react to international trends in MG+4C technology development, the NPIE has adopted a rolling-plan strategy to adjust the direction of its seven sub-

programs. The NPIE organizes annual strategic planning and review meetings, aggressively meets with industry leaders, gathers the recommendations of experts in various fields, and adjusts the direction and content of the overall planning to ensure the competitiveness of Taiwan's IC industry. With the amendment made in 2012, the NPIE has raised the importance of core technologies for smart handheld products, such as innovative system architectures, 3D memory architectures, and software for advanced application processors (APs), as well as energy-aware and intelligent sensing technologies.

With the ultimate goal to foster a leap of Taiwan's economics, the NPIE effectively integrates the R&D resources and capabilities of government, academia, and industry, aiming at developing core IC technologies, cultivating interdisciplinary talents, and exploring new MG+4C market. We believe that through implementation in all these dimensions, the NPIE will realize a better life and environment with innovative intelligent electronics and systems.

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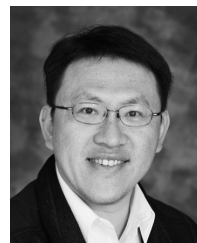
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