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Design of AM Self-Capacitive Transparent Touch Panel Based on a-IGZO Thin-Film Transistors

KEJUN WU[1], (Member, IEEE), JUN ZHANG[1], YUANBO LI[1], XIANGZHAN WANG[2], YANG LIU[2], QI YU[2], (Member, IEEE), AND TUPEI CHEN[1], (Member, IEEE)

[1]School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798
[2]State Key Lab of Electronic Thin Films and Integrated Devices, University of Electronic Science and Technology of China, Chengdu 610054, China

Corresponding author: Kejun Wu (kevinbest2010@163.com)

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ABSTRACT In this work, we propose a novel active-matrix self-capacitance touch panel circuit. Each touch pixel contains only one thin film transistor. The principle of the touch event detection is to detect the voltage change, which is caused by the change of electrode capacitance. The voltage sensing by capacitance sensor is converted to capacitive digital data which compare with default value to judge whether the touch event is touched or not. The simplest structure increase maximizes the sensing pad area and reduce the parasitic effects. An array of 5 × 5 capacitive sensing active-matrix self-capacitive touch panel based on the proposed solution is designed and implemented. The potential for high precision and high reliability is proven in the measurement results.

INDEX TERMS Touch panel, thin film transistor, high precision, high reliability.

I. INTRODUCTION

Touch panel has attracted a lot of attention in various applications, such as smart phones and tablet PCs [1]–[6]. It greatly narrows the distance between human and smart products. With the change of application environment, it puts forward more demands for the touch panel, which should have high precision and high reliability. There are three main approaches to realize this technology including photo detection type [7], resistive type [8]–[10], and capacitive type [11]–[13]. Photo detection touch panel determines the touch signal by using the light reflection or absorption. This method, which is sensitive to the ambient light, easily causes sensing noise [14]. The resistive touch sensors have the advantage of low cost. However, the poor reliability limits their potential [14]. Comparing with the above two types of touch mechanisms, the capacitive touch type is the main-stream interaction technology benefiting from the merits of high reliability, high sensitivity, and easiness for multi-touch sensing.

The conventional projected capacitive touch array is passive matrix (PM). The capacitance detection circuits detect the change of capacitance to distinguish the scanning line being touched or not. The method, however, is difficult to enhance the resolution due to the soaring parasitical and coupling capacitance as the touch element size scales down. To overcome the drawbacks of PM capacitive touch type, the active-matrix (AM) touch type is proposed [15]–[20]. The 1T1R1C (one transistor, one resistor and one capacitor) touch sensing circuit architecture is widely used in AM touch panel [14], [17]. The RC time constant changes induce pulse overlapping, which is used to judge whether the panel is touched or not. However, the RC time constant deviates from expected value because of the parasitical capacitance and resistor. Except that, the capacitor and resistor will increase the size of each touch panel element, causing the reduction of the precision of touch panel array. A high precision active-matrix self-capacitive touch panel is proposed in which each touch element consists of a self-capacitor electrode and a thin film transistor (TFT) [15]. The capacitor electrode connects to one source (or drain) electrode of TFT. The other drain (or source) electrode links the sensing column to capacitance detection circuits. However, the TFT is connected in series with the touch pad. The voltage value detected by the capacitive sensing circuit is strongly influenced by the performance of the transistor, such as the on-current. In addition, when the TFT is turned off, the touch panel electrode is not connected to any potential and is in a tri-state state. The charge

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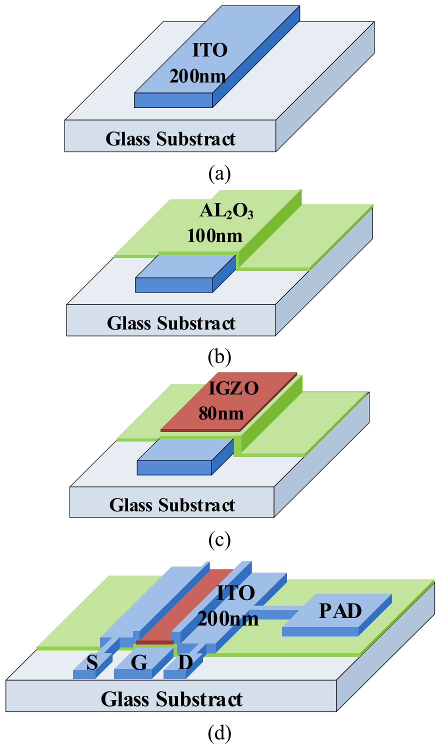

FIGURE 1. Schematic diagrams showing the evolution of the device cross-sections during the fabrication of the a-IGZO TFT touch panel.

accumulation effect in this state will affect the performance of the TFT. In severe cases, when the gate terminal control voltage of the TFT is high, the TFT will not turn on.

In this paper, we propose an AM self-capacitive touch panel. Same as [15], [16], each element is also controlled by a TFT. However, the TFT and the capacitor electrode are parallel connected in our proposed AM self-capacitive touch panel. The voltage change on the capacitor electrode cannot affect the work state of TFT. The TFT based on amorphous indium-gallium-zinc-oxide (a-IGZO) has high electrical performance, low process temperature and high optical transmittance. The self-capacitor in each element of the proposed touch panel can be switched on or off easily by the TFT, resulting in lower parasitical capacitance and hence higher resolution.

II. DEVICE FABRICATION

In this work, transparent a-IGZO was used as an active layer in TFT to achieve excellent electrical performance, low process temperature and high transparence. The process flow of a-IGZO TFTs and the evolution of the schematic cross section of each element are shown in Fig. 1. Firstly, an ITO glass is patterned and used as the gate electrode of TFT, as indicated in Fig. 1(a). The thickness of ITO thin film is 200nm. And then, a 100-nm-thick Al_2O_3 thin film was deposited by atomic layer deposition to form the gate dielectric of TFT at the temperature of 250° as shown in Fig. 1(b). And then, as shown in Fig. 1(c), a IGZO thin film with the thickness of ~80 nm was subsequently deposited on the Al_2O_3 thin film layer by radio-frequency sputtering in Ar ambient at room temperature using a-IGZO target (In:Ga:Zn mole ratio = 1:1:1). Finally, a 200 nm ITO thin film was deposited by RF magnetron sputtering and patterned to form the source and drain of TFT as shown in Fig. 1(d). The drain of TFT was connected to the ITO touch panel pad, which is fabricated together with the drain/source of TFT. A post-deposition annealing was conducted at 300° in N_2 atmosphere for 15 minutes.

III. TOUCH SENSING CIRCUIT

A. PROPOSED TOUCH SENSING CIRCUIT

The proposed AM self-capacitance touch panel pixel circuit is shown in Fig. 2(a). Only one TFT is used in touch sensing circuit. The touch panel works on the principle of self-capacitive sensing. Each touch element consists of a self-capacitor electrode, which is connected to the drain electrode of an a-IGZO TFT and capacitance sensing circuits. The source of TFT is connected to the ground. The voltage (V_{GD}) scanning row from the gate driving circuit is connected to the gate electrode of TFT to control the ON/OFF state of the TFT. When a finger touches on the ITO touch electrode, a capacitor is formed and connected in parallel between the electrode and the finger which acts as the virtual ground. As shown in Fig. 2(b), when a scanning voltage pulse with low voltage level is applied to the corresponding row, the TFT is in OFF state. This capacitor is sensed by the capacitance sensing circuit. Otherwise, when scanning voltage pulse with high voltage level is applied to the corresponding row, the TFT is in ON state. The capacitance sensing circuit does not detect touch electrode signals. The basic capacitance measurement technique is to charge up the capacitor C on one electrode input with a DC current I for a charge time T. The capacitor C is the total capacitance on the electrode including touch electrode capacitance, touch capacitance from a finger or capacitive pen and parasitic capacitor. Before measurement, the electrode input is grounded, so the electrode voltage starts from 0 V and charges up with a slope, which can be express as

$$\frac{dV}{dt} = \frac{I}{C} \tag{1}$$

All of the other row electrodes are grounded during this measurement. At the end of charge time T, the electrode voltage is measured by an analog-to-digital converter (ADC). The relationship between electrode voltage and capacitance can be expressed as

$$V = \frac{I \times T}{C} \tag{2}$$

According to (2), the voltage is inversely proportional to capacitance. The electrode is then discharged back to the ground level at the same charging rate. From (2), when a touch event occurs, a touch capacitor presents in parallel with the electrode capacitor and parasitic capacitor. Therefore, the value of total capacitance increases. With the same charge time and charge current, the peak voltage of a touch event

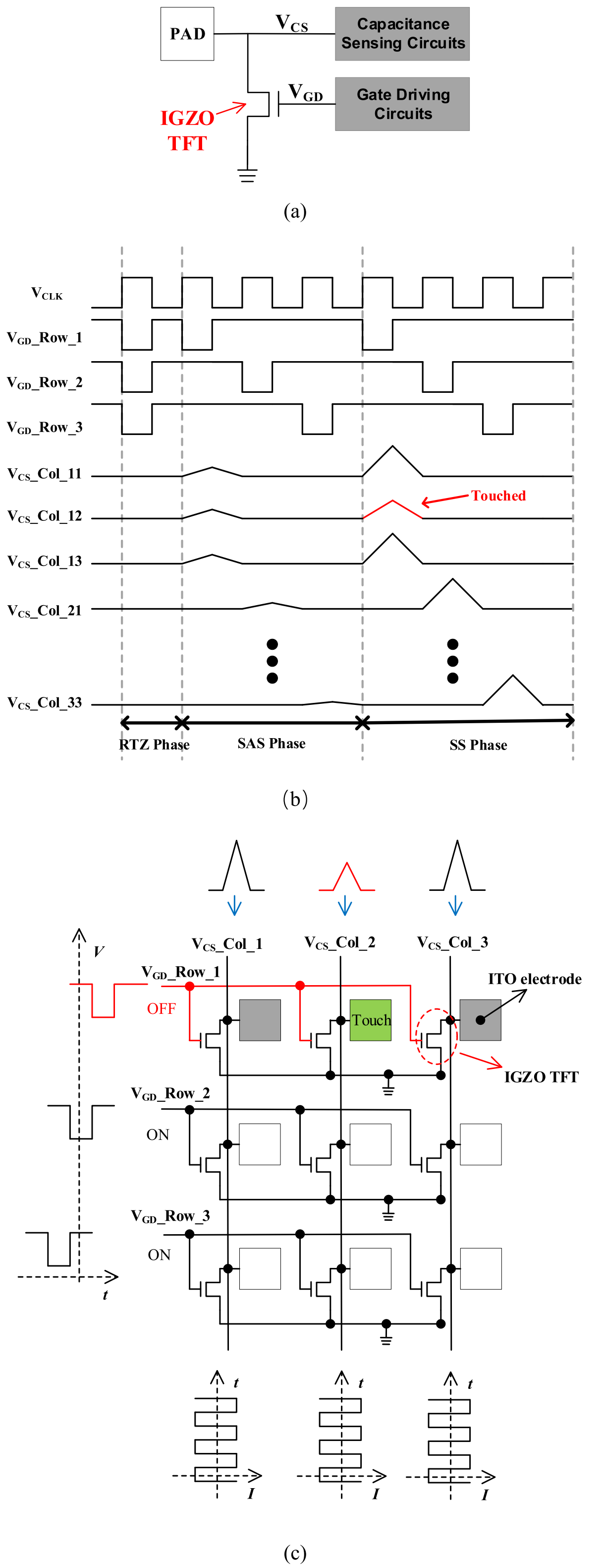

FIGURE 2. (a) Proposed touch panel circuit. (b) Timing diagram. (c) Schematic structure and working principle of the AM self-capacitive touch panel.

sensed by the capacitance sensing circuit is smaller than the peak voltage without the touch event. As shown in Fig. 2(c), a block of a 3 × 3 touch panel array is used to demonstrate the working principle of the proposed AM self-capacitance touch panel array. When power on and in the first clock cycle, the system is in the reset to zero (RTZ) phase as shown in Fig. 2(b). All gate control singles are set to low. Therefore, all nine TFT are turn on, and all touch pad connect to ground. And then, the system is in the sample and store (SAS) phase. There are three clock cycle for three rows. Take the first cycle as an example, the control single $V_{GD}\_Row\_1$ from high to low state, all TFT in the first row are in the OFF state. The capacitance sensing circuits sample the capacitor of three touch pad respectively. The voltage on the capacitor is quantized into digital data by the ADC and stored in registers. At same time, the TFTs in the other two rows are ON state and connected to ground. After three clock cycle, all voltage on the capacitors are sampled and quantized into digital data. The digital data are stored in registers. The voltage on the touch pad, V_{CAP}, can be expressed as

$$V_{CAP,ij} = \frac{I_{ij} \times T}{C_{tot,ij}} \tag{3}$$

where i and j is the number of row and column. C_{tot} is the total capacitance, including the coupling capacitor of the touch pad and the connect lines, and all the parasitic capacitor. Due to the layout or process mismatch, the value of the capacitor in the touch panel array is different. This will affect the judgment results of touch events. As shown in (3), for different capacitors C_{tot}, the same sensing voltage can be obtained by adjusting the value of charge current. The effect for the different mismatch of capacitor are eliminated.

And then, the system is in the touch events sensing (SS) phase. Same as SAS phase, the three row capacitors on the touch pad are sensed by the capacitance sensing circuit one by one. The voltage on the touch pad is sampled and quantized into digital data which is recorded with the row number. Meanwhile, the digital capacitive data of each column converted from the sensing circuit is transferred together with the position information (i.e., the row and column numbers) to a PC for processing and display. As shown in Fig. 2(c), the green and gray ITO electrodes represent the touched center and around elements at the scanning row, respectively. Due to the increase of total capacitance when a touch event occurs on the ITO electrode, the peak voltage of the touch event sensed by the capacitance sensing circuit is smaller than the peak voltage without the touch event.

B. THE ADVANTAGES OF THE PROPOSED TOUCH SENSING CIRCUIT

One of the values of the proposed AM self-capacitance touch panel circuit is less affected by parasitic effects. According to (2), the voltage sensed by capacitane sensing circuit is only related to the capacitance value, charging current and charging time. There is no current path from the capacitor detection terminal to ground, so the effect of parasitic resistance is negligible. On the other hand, when the system is in touch detection state, only the capacitor of one row is detected while the capacitor in other rows are connected to ground.

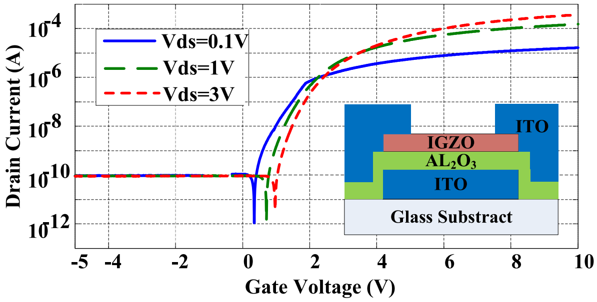

FIGURE 3. Transfer characteristics (I_d versus Vg) of TFTs.

Therefore, the crosstalk coupling capacitance is very small. Except that, parasitic capacitor can be detected and corrected when the system power is turned on. Therefore, the influence of parasitic capacitor can be easily eliminated in our proposed AM self-capacitance touch panel system.

Moreover, the proposed AM self-capacitance touch panel circuit only has one TFT in one touch panel element. This structure has significant advantages in improving the integration and transparency of the touch panel array. In the literature [15], [16], only one TFT is used in the touch panel unit circuit. However, the TFT is connected in series with the touch pad. The voltage value detected by the capacitive sensing circuit is strongly influenced by the performance of the transistor, such as the on-current. In addition, when the TFT is turned off, the touch panel electrode is not connected to any potential and is in a tri-state state. The charge accumulation effect in this state will affect the performance of the TFT. In severe cases, when the gate terminal control voltage of the TFT is high, the TFT can not be turned on. In our proposed touch panel circuits, the three-terminal of TFT has fixed state at any time. The charge accumulation effect has no effect on circuit function. Therefore, the proposed touch sensing circuit has the advantage of high reliability.

IV. MEASUREMENT RESULTS AND DISCUSSION

Typical transfer characteristics of a-IGZO TFTs fabricated on glass substrate are shown in Fig. 3. The channel width and length of the TFT device are about 40μm and 20μm, respectively. The gate voltage (V_G) sweep from -5V to 10V at the drain voltage (V_D) of 0.1, 1 and 3 V, respectively. The ON/OFF ratio of the drain current (I_D), field-effect mobility (μ), and subthreshold swing (S.S) that are obtained from the transfer curve are 1.8×10^5, 15.8 cm^2/V·s, and 0.5 V/dec at the drain voltage (V_D) of 0.1V, respectively. When the gate voltage is 10V, the drain current is more than 10μA, 100μA and 360μA with the drain voltage of 0.1V, 1V and 3V, respectively. This value of current is enough to charge/discharge the capacitors on the electrode within the set time in our proposed touch panel architecture.

Fig. 4 shows a block diagram of the whole proposed AM touch system, including the monitor, micro control unit (MCU), gate driver, capacitance sensor and touch panel array. The 5×5 touch array connects with the gate driver and capacitance sensor by the flexible PCB connection board.

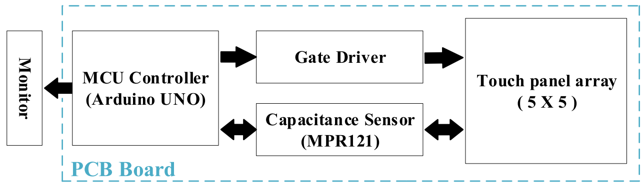

FIGURE 4. Block diagram of the architecture of the proposed AM touch system circuits.

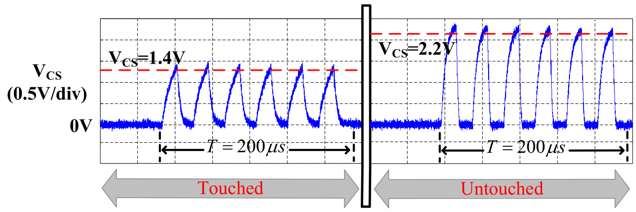

FIGURE 5. Measurement result of the sensing circuit.

An Ardunio UNO is used as the MCU controller that informs the gate voltage driver to scan the row and records the corresponding row number. At the same time, capacitance sensor (Freescale's MPR121) detects the voltage value of the pad capacitance, and the voltage value is then converted to digital data by the ADC integrated in MPR121. And then, the position information of row and column is transferred to the MCU controller for processing and display on the monitor.

Fig. 5 shows the measurement result of the sensing circuit. When a touch event occurs, as described in above, a touch capacitor is formed and connected in parallel with the electrode capacitor. Therefore, the total capacitance increases. The sensing voltage decreases with the same charging time and charging current. As shown in Fig.5, the pulse voltage sensed by the capacitance sensor (MPR121) is 1.4V when a touch event occurs. If there is no touch event occurring, the total capacitance is that of the electrode capacitor and the pulse voltage is 2.2V. By using the equation (2) and (3), when the charge current I is 29μA, T is 16μs, the value of capacitor before and after the touch event are 210.9 pF and 331.4pF, respectively. Within each row selection cycle, the capacitance sensor (MPR121) will perform 6 times of charging and discharging cycles. Therefore, the voltage is sampled for 6 times in one row selection cycle. The maximum and minimum voltage values obtained from the voltage sampling are abandoned, and only the remaining 4 voltage values from the sampling are averaged. The averaged value is used as the detected voltage of one electrode capacitor. This operation can effectively avoid false touch events and improve touch detection accuracy.

Fig. 6 shows a demonstration of the proposed touch panel with a 5×5 touch array. The thickness of cover glass and the ITO connect line are 0.8mm and 200nm, respectively. The frame rate is 2ms. It can be seen that the touch function is realized in this demonstration. Touch points can be accurately identified. In this demonstration scheme, in order to facilitate the testing of the function and electrical characteristics of each TFT, the gate and drain of the all transistors are

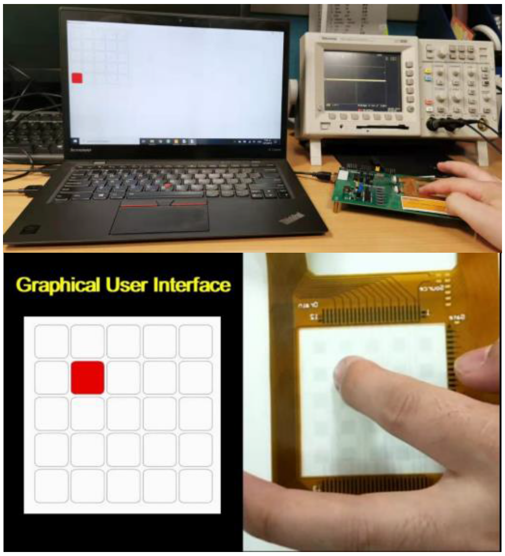

FIGURE 6. Demonstration of the 5 × 5 touch panel

independently controlled. This will increase the number of connection lines. However, the voltage control of both the row and column implemented as shown in Fig. 2(c) is very easy. Only the timing of the voltage control signal in the MCU needs to be modified.

V. CONCLUSION

In this work, an AM self-capacitance touch panel based on a-IGZO TFTs has been demonstrated. This panel works on the principle of switched self-capacitive sensing and has several advantages. Firstly, a-IGZO TFT used in this system is not only due to its transparent property but also its high electron mobility, low-temperature fabrication process, good uniformity and high reliability. Secondly, the present touch panel uses only one TFT in one pixel, which has the potential for application in high resolution touch panel. Moreover, the proposed circuit structure has high system stability because the TFTs used in the circuit are prevented from being in a tri-state state, which is the major advantage over the other schemes of active touch panels. A 5 × 5 touch panel based on the proposed circuit structure is successfully designed and measured. The proposed circuit provides a useful way to implement high precision AM self-capacitance touch panel.

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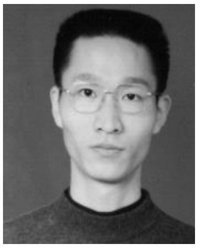
KEJUN WU (Member, IEEE) was born in Sichuan, China. He received the B.S. degree in integrated circuit design and integration system from the Chengdu College, University of Electronic Science and Technology of China (UESTC), in 2010, and the Ph.D. degree from the School of Electronic Science and Engineering, UESTC, in 2017. He also performed research as a Research Staff with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore, in 2018. He currently holds a Postdoctoral position with the UESTC. His current research interests include semiconductor devices design and application, AD/DA mixed integrated circuit, and optoelectronic integrated circuit (OEIC).

JUN ZHANG received the bachelor's and master's degrees from the University of Electronic Science and Technology of China (UESTC), in 2010 and 2013, respectively, and the Ph.D. degree from Nanyang Technological University (NTU), in 2017. He is currently a Research Fellow with NTU. His current research focuses on the optical properties of thin films in the applications of renewable energy.

YUANBO LI received the bachelor's degree from the Wuhan University of China (WHU), in 2016, and the M.Sc. degree from Nanyang Technological University (NTU), in 2017, where he is currently pursuing the Ph.D. degree. His research focuses on the transparent or flexible thin-film transistor fabrication and its applications.



XIANGZHAN WANG received the Ph.D. degree in microelectronics and solid state electronics from the University of Electronic Science and Technology of China (UESTC), in 2010. He is currently with the State Key Laboratory of Electronic Thin Films and Integrated Devices, UESTC.

YANG LIU received the B.S. degree in microelectronics from Jilin University, Changchun, China, in 1998, and the Ph.D. degree from Nanyang Technological University, Singapore, in 2005. In 2008, he joined the School of Microelectronics, University of Electronic Science and Technology of China (UESTC), Chengdu, China, as a Full Professor. He has authored or coauthored over 130 peer-reviewed journal articles and over 100 conference papers. His current research interests include memristive neural network systems and neuromorphic ICs. In 2006, he received the Prestigious Singapore Millennium Foundation Fellowship.

QI YU (Member, IEEE) was born in Yantai, Shandong, China, in 1972. He received the master's and Ph.D. degrees from the University of Electronic Science and Technology of China, in 1997 and 2010, respectively. In 2011, he was promoted to Professor. Sponsored by the China International Talent Exchange Foundation, he had been to IMEC for the Integrated Circuits Design Training Program for three months, in 2007. Since 1997, he has been accomplishing more than 20 items research projects in the fields of semiconductor devices and integrated circuits. He has published about 30 articles on international conferences and publications. He holds five China invention patents. His main research interests focus on novel semiconductor devices and mixed signal integrated circuits design. He received the Third Award of Science and Technology of Progress of Information Industry Ministry of China.

TUPEI CHEN (Member, IEEE) is currently an Associate Professor with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. He is the author or coauthor of more than 270 peer-reviewed journal articles, more than 130 conference presentations, one book, and six book chapters. He has filed nine U.S. patents and 11 technology disclosures. His research areas include the applications of nanoscale materials in electronic devices, photonic devices and renewable energy, novel memory devices, memristor and its application in artificial neural networks, Si photonics, and metal oxide thin films and their applications in flexible/transparent devices.