Flexible, Large-Area, and Distributed Organic Electronics Closely Contacted with Skin for Healthcare Applications

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***Abstract*— Flexible, large-area, and distributed sensor and/or actuator array closely contacted with the human skin are human-friendly and sophisticated tools for biomedical and healthcare applications. In this paper, new applications and design solutions in organic electronics are shown. In an insole pedometer with piezoelectric energy harvesters, an all-pMOS negative voltage generator for a pseudo-CMOS inverter is shown. In a surface electromyogram measurement sheet for the prosthetic hand control, a post-fabrication select-and-connect method to reduce the transistor mismatch is shown. In a flexible wet sensor sheet to detect the urination in diapers, ESD protection with organic schottky diodes is shown.**

I. INTRODUCTION

Wearing-unconscious devices are required for biomedical and healthcare applications, because bulky devices closely contacted with the human skin irritate users. The organic electronics enables flexible, large-area, and distributed sensor and/or actuator array and is suitable for the wearing-unconscious devices. Fig. 1 shows our developed flexible and large-area applications using organic transistors [1-11]. In this paper, new healthcare applications including an insole pedometer with piezoelectric energy harvester, a surface electromyogram measurement sheet for the prosthetic hand control, and a flexible wet sensor sheet to detect the urination in diapers are shown. New design solutions for the organic electronics are also shown.

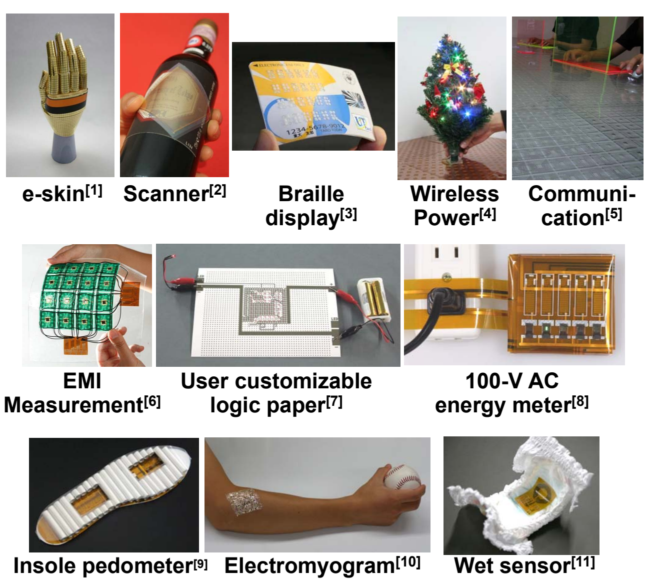

Fig. 1. Developed flexible and large-area applications using organic transistors [1-11].

II. INSOLE PEDOMETER WITH PIEZOELECTRIC ENERGY HARVESTER [9]

A. Overview of Insole Pedometer

Fig. 2 shows a photograph of the proposed insole pedometer [9] including the piezoelectric energy harvester and the 2V organic PMOS rectifier and counter. A polyvinylidene difluoride (PVDF) sheet is used as the piezoelectric energy harvester. Twenty-one rolls of PVDF film are embedded in the insole. Each time the insole is pressed by the foot during walking, the harvested energy is rectified by the organic rectifier and the number of the steps is counted by the organic

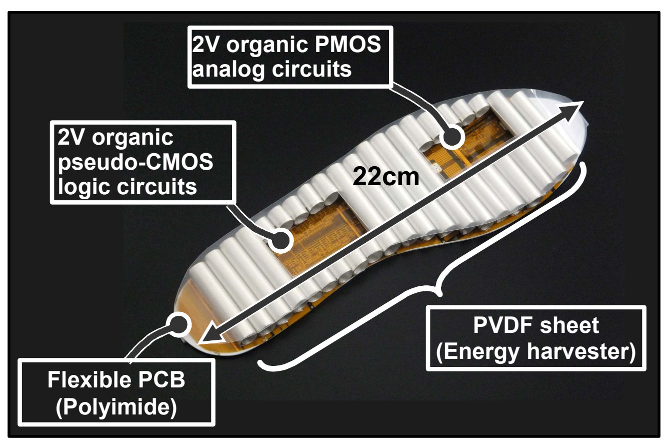

Fig. 2. Insole pedometer with piezoelectric energy harvester.

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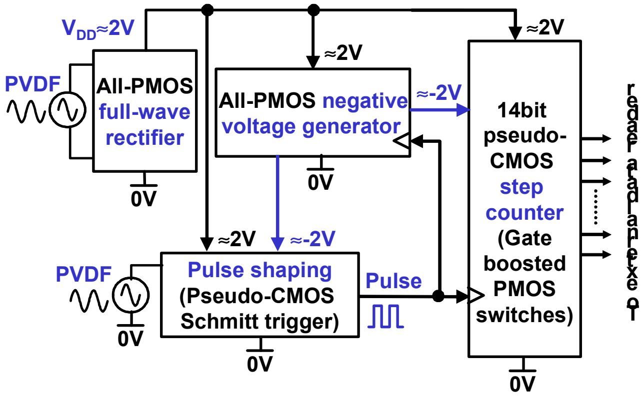


Fig. 3. Block diagram of insole pedometer.

counter.

Fig. 3 shows a block diagram of the proposed organic insole pedometer. It consists of four circuit blocks. The all-PMOS full-wave rectifier supplies a voltage V_{DD} of approximately 2V to all circuit blocks. In the clock generator, the output of the PVDF harvester is half-wave-rectified and a Schmitt trigger inverter converts the half-wave-rectified signal into a clock signal. The generated clock signal is sent to both the PMOS negative voltage generator and a 14-bit Pseudo-CMOS counter with gate-boosted PMOS switches. The negative voltage generator supplies a voltage V_{SS} (e.g., -2V) to the counter.

B. All-PMOS Negative Voltage Generator for Pseudo-CMOS Inverter

In organic circuit design, PMOS-only circuits are often used, because the mobility of PMOS transistors is much higher than that of NMOS transistors in our process. As shown in Fig. 4, a Pseudo-CMOS inverter [9] that consists of four PMOS transistors has high gain, but it requires a negative voltage bias. In energy-harvesting applications, however, a single power supply is typical. Therefore, in this work, to increase the noise margin of PMOS-only logic circuits, a negative voltage is generated by a charge pump and is applied as the bias of Pseudo-CMOS inverters.

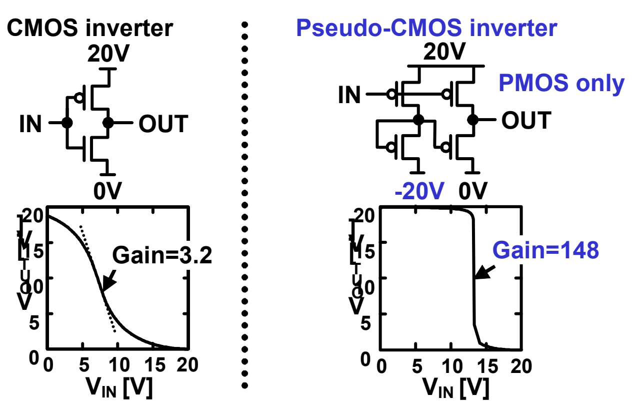
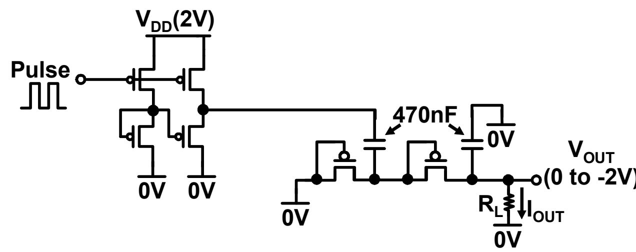
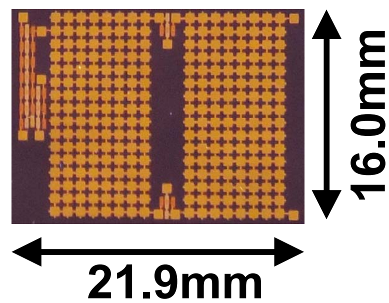


Fig. 4. Organic circuits. (a) Conventional CMOS inverter. (b) Proposed Pseudo-CMOS inverter.

Figs. 5(a) and (b) shows a schematic and a photo of the proposed all-PMOS negative voltage generator, respectively, which consists of a Pseudo-CMOS inverter, two diode-connected PMOS transistors, and two MIM capacitors. The measured waveforms are shown in Fig. 6. The output voltage (V_{OUT}) of the negative voltage generator is -1.6V in the case of 10Hz clock pulses and can provide a power of at least 10μW power to the load circuit.



(a)



(b)

Fig. 5. (a) Schematic and (b) photo of proposed all-PMOS negative voltage generator.

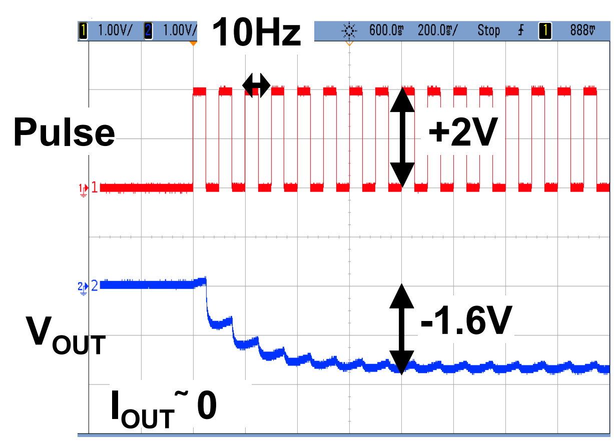


Fig. 6. Measured waveforms of negative voltage generator.

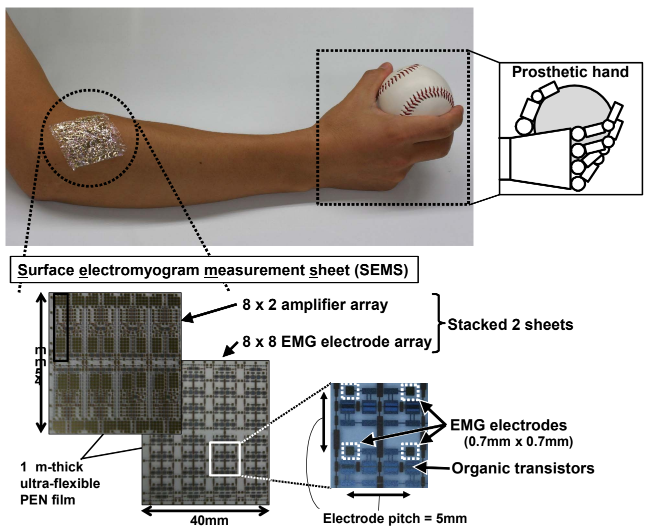


Fig. 7. Surface EMG measurement sheet.

III. Surface Electromyogram Measurement Sheet for Prosthetic Hand Control [10]

A. Overview of Electromyogram Measurement Sheet

A surface EMG measurement sheet [10] on which an EMG electrode array and a front-end amplifier array with 2V organic transistors are integrated on a 1µm-thick ultra-flexible film is developed to control prosthetic hands. Fig. 7 shows a photograph of the developed 45x40mm^2 64-channel SEMS. In SEMS, an 8x8 EMG electrode array sheet and an 8x2 front-end amplifier array sheet with 2V organic transistors on a 1µm-thick ultra-flexible polyethylene naphthalate (PEN) film are stacked.

B. Post-Fabrication Select-and-Connect (SAC) Method to Reduce Transistor Mismatch

One of the design challenges of organic circuits for the amplifier array is the mismatch of amplifiers due to the large mismatch of organic transistors. To solve the problem, the post-fabrication select-and-connect (SAC) method that reduces the transistor mismatch is proposed. Figs. 8(a) and (b) show conventional and proposed transistor mismatch reduction techniques for the amplifier array, respectively. In the SAC method, first, the I-V characteristics (e.g., threshold voltage and ON-current (I_{ON})) of each transistor are measured. 2N measurements are required. Then, N_1 and N_2 transistors are selected from the left and right groups in Fig. 8(b), respectively, on the basis of the results of calculation to minimize the target mismatch. N_1 and N_2 are not always equal. Finally, the selected N_1 (N_2) transistors are connected by inkjet-printed interconnects, as shown in Fig. 8(c). Although the proposed SAC is too costly and impractical in the silicon VLSI technology, the SAC takes advantage of the printed electronics. Fig. 8(d) shows the simulated N dependence of I_{ON} mismatch. Compared with the conventional parallel transistors, the proposed SAC reduces the I_{ON} mismatch by 54%, 92%, and 99.7% at N = 2, 4, and 8, respectively.

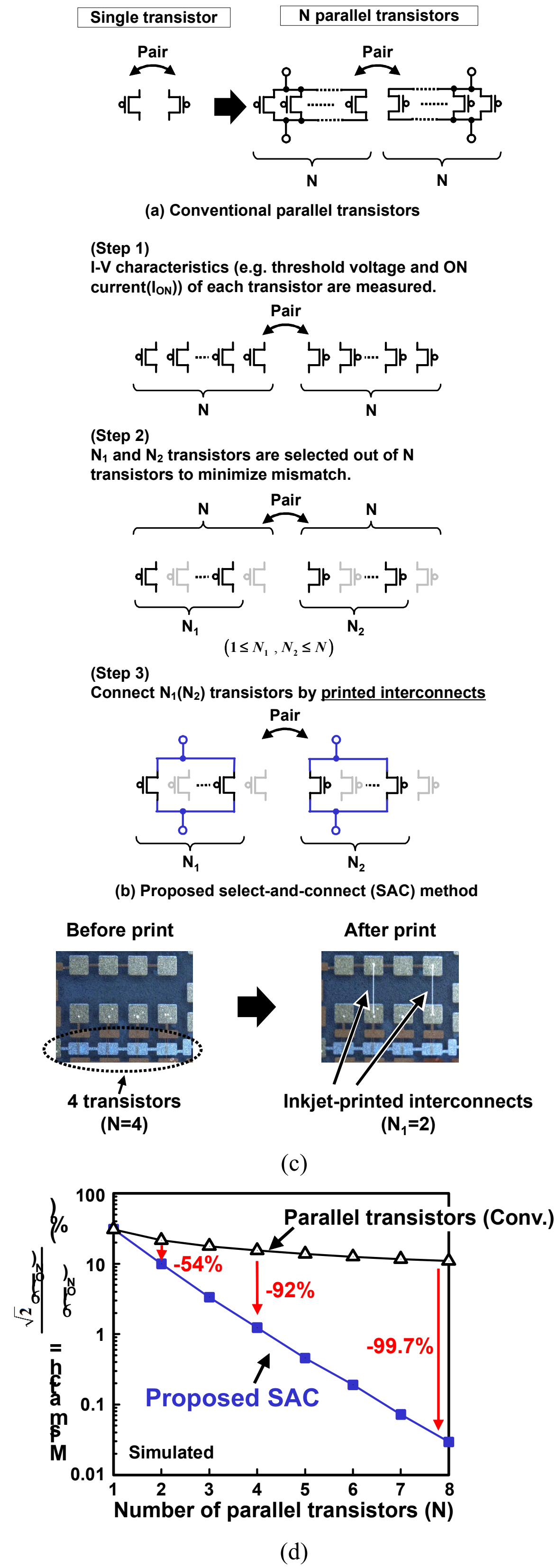


Fig. 8. Conventional and proposed transistor mismatch reduction techniques.

IV. Flexible Wet Sensor Sheet to Detect Urination in Diapers [11]

A. Overview of Wet Sensor Sheet

An organic transistor based flexible wet sensor sheet (FWSS) with wireless power and data transmission using 13.56MHz magnetic resonance is developed to detect urination in diapers [11]. Fig. 9 shows a photograph of the developed 78mm x 53mm FWSS. In its actual implementation, the FWSS is embedded in the cotton of a diaper, although FWSS is placed on the surface of the diaper in Fig. 9 for clarity. The FWSS is a passive transponder that is wirelessly powered by a reader and sends sensor data to the reader. In the FWSS, organic circuits fabricated on a 12.5µm-thick flexible polyimide film are stacked on 40mm square coil on 12.5µm-thick flexible PCB. Fig. 10 shows a circuit schematic of the FWSS and reader. The reader is expected to be attached to the pants near the diaper. The reader wirelessly transmits power between the coils via magnetic resonance at 13.56MHz. In this work, instead of conventional electromagnetic induction, magnetic resonance is used to increase the distance between the reader and FWSS.

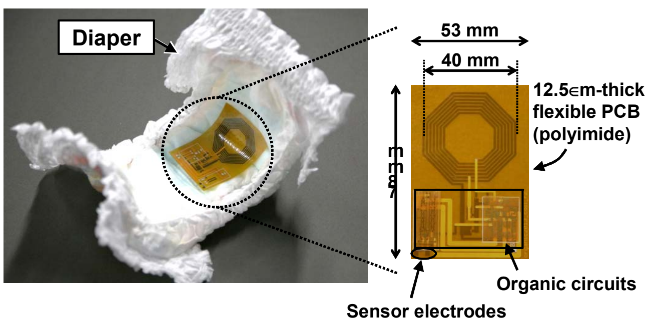


Fig. 9. Flexible wet sensor sheet (FWSS).

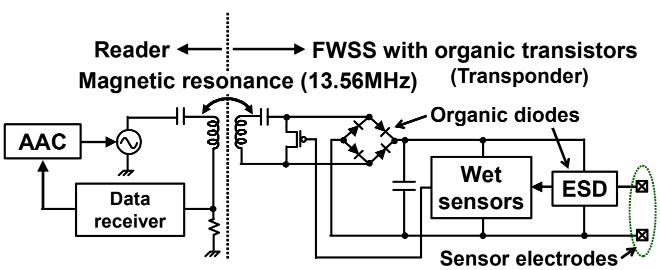


Fig. 10. Block diagram of flexible wet sensor sheet.

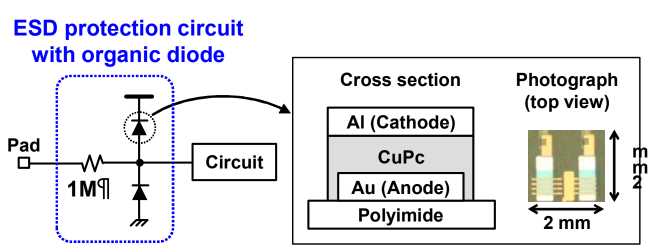


Fig. 11. ESD Protection with organic schottky diode.

B. ESD Protection With Organic Schottky Diode

ESD protection is essential in the FWSS because the electrodes can directly come in contact with wet human skin. ESD protection in organic transistors, however, is difficult because they are fabricated on an insulating film . To solve the problem, ESD protection with organic Schottky diodes using copper phthalocyanine (CuPc) in Fig. 11 is proposed. With the ESD protection, the ESD tolerance is above 2kV, which successfully satisfies level 1 of IEC 61000-4-2.

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