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Feasiblity of Low-Power Organic Buskeeper PUF using Low-Voltage-Operation Complementary Organic TFT

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Abstract—This paper demonstrates physical unclonable function (PUF) implementation using complementary organic transistors operating at low-voltage. PUF is one of the essential elements of security, and is important for various application of organic devices. We implement a simple buskeeper PUF, which consists of two complementary transistor pairs. We confirmed that PUF bit values implemented using organic transistors can be read at a standard voltage of electronic circuits (3.3V) via common circuit board interface. We also observed low static current consumption (11.8μA) of PUF chip.

1. Introduction

Organic device is regarded as one of the prospective new devices in coming IoT era because of its features like flexibility, printability, large area implementation, and so on. There are many implementation of thin-film transistor (TFT), light emitting diode (LED), and sensors using organic devices.

On the other hand, security of software, hardware, sensor, or network is becoming important issue in IoT. What is the basis or the security of the device, which is also called "root of trust", is an important issue of security, and PUF is a candidate of a root of trust at hardware level. PUF generates identification information unique to each chip, and can identify each chip fabricated with the same process and mask. Organic device has many prospective applications, and implementation of hardware security will also be important.

This paper investigates the feasibility of PUF using organic printable devices. A buskeeper PUF [2] is implemented using organic device, and low voltage operation at 3.3V of organic PUF circuit is verified. Power consumption, output speed, and interface between organic devices and common electronic circuits will be evaluated.

2. Device structure

In this paper, semiconductor materials of p-type and n-type organic TFT devices are DNTT [5] and TU-1 [6] respectively. Figure 1 shows cross-sectional structures of of p-type and n-type devices. Devices [5, 7] consists of Al bottom gate electrode layer (gate), AlO_x insulator layer, self-assembled monolayer (SAM) layer, organic semiconductor layer, and Au top source or drain electrode. As AlO_x and SAM layers are sufficiently thin (4-nm and 2-nm thickness respectively), devices operate at low voltage around 3V or lower [5]. Though TFT devices are fabricated with thermal deposition in this paper, fabrication process can be replaced with printing technologies in future as materials are developed considering compatibility with printing technologies.

3. Buskeeper PUF

In this paper, we adopt buskeeper PUF [2]. Figure 2 shows the structure of the buskeeper PUF. Buskeeper PUF consists of two inverters and can be implemented with low design cost. In addition, by using symmetric layout implementation and additional two buffers fine randomness is easily obtained [3]. Buskeeper PUF is composed of complementary devices, static power consumption will be suppressed in comparison with non-complementary PUF implementation [4]. As buskeeper PUF is composed of simple logic gates, buskeeper PUF is suitable for feasibility evaluation of complementary logic cell operation of organic TFT devices.

4. Test chip, chip-to-board interface, and measurement environment

Figure 3 shows a photo of the fabricated organic PUF chip, where off-chip interface flat cable is attached, and Fig. 4 depicts the structure of buskeeper PUF chip. 90-bit buskeeper PUF cells are implemented on a chip. Gate widths of p-type and n-type TFTs of inverters are 200μm and 800μm respectively.

The buffer inverters of PUF bit is connected to 4 sets of 32-bit contact pads, and drive external interface cable or wire on an external multiplexer board. The test chip is connected with the multiplexer board via flat cables. Flat cable is attached to each of 32-bit contact pads sets using anisotropic conductive film. Multiplexer board has a flat cable connector. A multiplexer board contains 32-bit to 1-bit multiplexer and outputs 1-bit of 32-bit to an oscilloscope for measurement. Multiplexer address is given from an external pattern generator.

5. Measurement and evaluation

We here demonstrate evaluation of a buskeeper PUF chip using complementary organic TFT devices. Figures 6 and 7 show observed output waveform of buskeeper PUF bit via a flat cable and a multiplexer board. Output voltage of full power supply or ground swing is obtained at about 10 bits (ex. upper left bit address 9, lower left address 13). This result means that current device is capable of inverter and buskeeper PUF operation, and ground-to-power supply swing will be obtained at sufficient number of bits by variability control and circuit design optimization. Figure 8 shows a map of measured buskeeper PUF bit result when 0/1 threshold voltage is assumed to be 0.4V. Figures 9 and 10, and Tab. 11 show evaluation results of measured PUF in several criteria. Though device operation itself is not sufficient, inter-HD distribution and entropy results are relatively fine. Static current of 90-bit buskeeper PUF organic chip at 3.3V was 11.8μA, and low power consumption at low voltage is achieved. Fig. 11 shows rise and fall waveform of buskeeper PUF output via multiplexer board and flat cable. In spite of large load of external interface, organic device inverter of buskeeper PUF buffer drives signal in about 200ns.

6. Conclusion

We implemented and measured buskeeper PUF chip in organic device process. Measurement results verified that feasibility of logic operation of complementary organic TFT, fine PUF

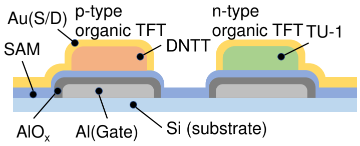

Fig. 1. p-type and n-type organic TFT device structure.

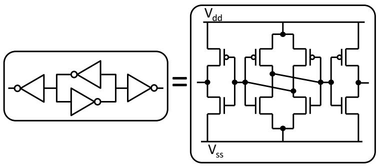
Fig. 2. Structure of buskeeper PUF.

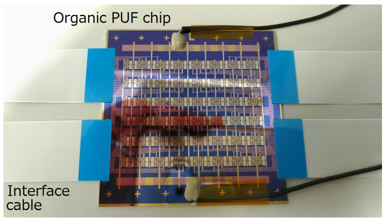

Fig. 3. Photo of organic PUF chip.

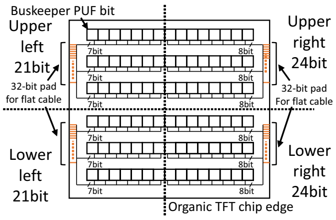

Fig. 4. Circuit implementation of organic PUF chip.

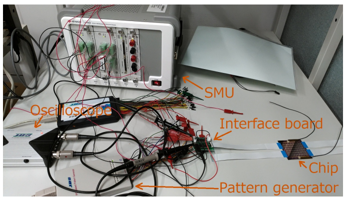

Fig. 5. Measurement environment.

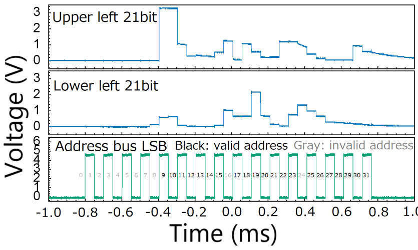

Fig. 6. Measurement result of 90-bit buskeeper PUF via four 32-bit cable. Results of upper left 21 bit and lower left 21 bit.

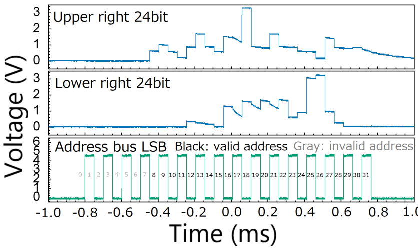

Fig. 7. Measurement result of 90-bit buskeeper PUF via four 32-bit cable. Results of upper right 24 bit and lower right 24 bit.

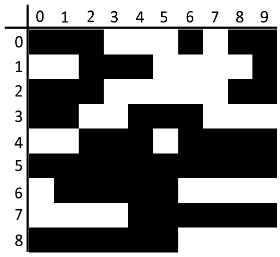
Fig. 8. Measured buskeeper PUF bits (white=0, black=1).

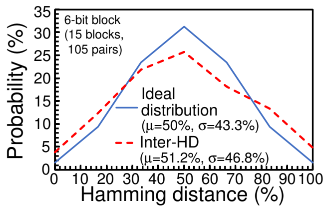

Fig. 9. Inter-HD distribution of measured bits. Block size = 6-bit.

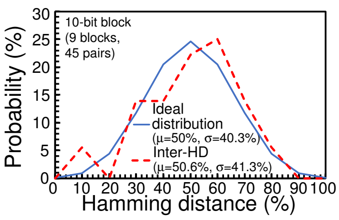

Fig. 10. Inter-HD distribution of measured bits. Block size = 10-bit.

inter-HD average (6bit)	50.2%
inter-HD std. dev. (6bit)	46.8%
inter-HD average (10bit)	50.6%
inter-HD std. dev. (10bit)	41.3%
Shannon entropy (1bit)	0.9710
Shannon entropy (2bit)	0.8031
Shannon entropy (3bit)	0.7904
Shannon entropy (4bit)	0.7538
Min entropy (1bit)	0.7370
Static current (3.3V)	11.8μA

Table I Inter-HD (hamming distance) and entropy evaluation results of measured buskeeper PUF bits.

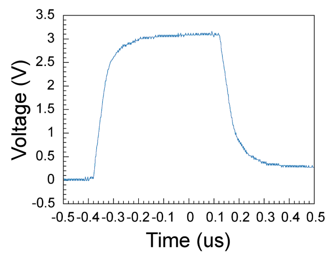

Fig. 11. Rise and fall waveforms.

performance, low power consumption (11.8μA), and sufficient external interface signal speed (200ns).

Acknowledgement

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