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Study of Organic Buskeeper-type Physically Unclonable Function on Flexible Substrate

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Abstract

We have investigated organic physically unclonable function (PUF) with organic buskeeper circuit on flexible substrate. To use flexible polyimide film and to reduce operation voltage up to 2 V, we use self-assembled monolayer formed by low temperature process as a gate dielectric. Finally, we obtained 2-V operation organic buskeeper PUF on flexible substrate. Bit error rate for 21 bit ID is 9.5%. Average inter hamming distance of this 21 bit buskeeper PUF is 7.3 bit among 4 chips.

1. Introduction

Recently, physically unclonable function (PUF) is paid attention to as core technology of a security device[1]. The PUF utilizes variation of characteristics in its own circuit to generate random number or hidden function to avoid security attack from outside. This unique mechanism suits a society which has communication among a lot of devices, like as inter net of things community. PUF system has been intensively studied on the field of silicon technology. However, few researches on PUF with organic electoronics have been reported to the best of my knowledge. We have already investigated organic ring oscillator PUF, and reported bit error rate of ID generation is low enough to use[2]. In the next step, we aim to study another PUF system not with signal delay as ring oscillator, but with circuit output difference[3]. SRAM circuit matrix called buskeeper circuit has been studied as the balance-type PUF[4]. In this study, we fabricate 90 SRAM on flexible substrate, and evaluate its bit error rate of ID generation and uniqueness.

2. Experimental

Fabrication process

Fig. 1(a) shows schematic cross-section structure of organic TFT which is used as basic components in buskeeper circuit. Organic buskeeper PUF is composed of thin film transistor (TFT) which is fabricated by thermal deposition process and solution process. Fig. 1 shows schematic cross-section structure of organic TFT. At first, we deposit aluminum onto polyimide base substrate by thermal evaporation. This layer is utilized as gate electrodes and part of circuit wiring. In the next step, we deposit Au pad onto aluminum electrode as blind via structure. After that, substrate is exposed to oxygen plasma treatment to form aluminum oxide layer which works as a part of gate dielectric in organic TFTs. Subsequently, we immerse the substrate into 2-propanol solution of self-assembler, n-octadecylphosphonic acid to form self-assembled monolayer (SAM) only on aluminum oxide, selectively[5]. In this process, concentration of 2-propanol solution of n-octadecylphosphonic acid is 5 mM. After 2 hours immersion, the substrate is rinsed by 2-propanol, and annealed at 100 degC. with hotplate.

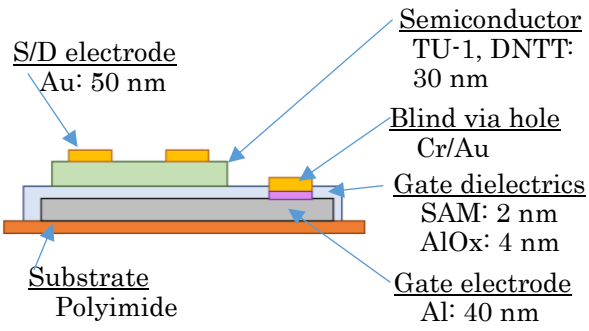

Fig. 1 Schematic TFT structure.

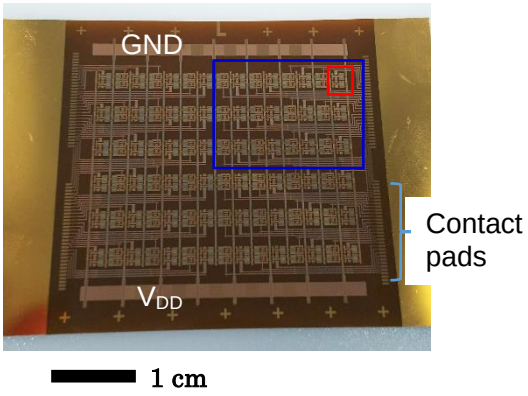

Fig. 2 Picture of busckeeper PUF. Red square shows size of one SRAM cell, and blue one shows size of one imaginary chip of buskeeper PUF. One chip has 21 or 24 contact pads connected to output terminal of SRAMs.

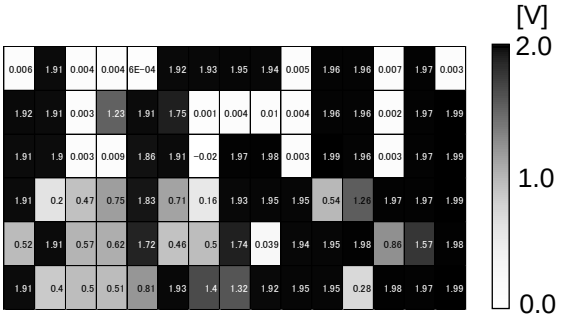

Fig. 3 Spatial distribution of output voltage in buskeeper PUF. Values in each cell are output voltage of SRAM in buskeeper PUF. Cells are colored by voltges of corresponding SRAM in gray scale.

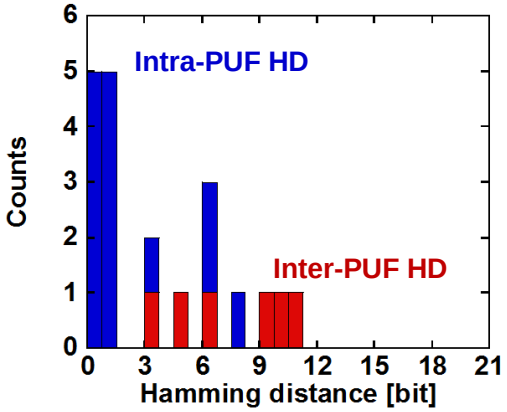

Fig. 4 Histogram of Inter and intra Hamming distance.

Dinaphtho[2,3-b:2',3'-f]thieno[3,2-b]thiophene (DNTT, SigmaAldric Co. LLC)[6] and benzobis(thiadiazole) derivative (TU-1, Futureink Co.)[7] are deposited on self-assembled monolayer gate dielectric by thermal evaporation as p-type and n-type organic active layer, respectively. Finally, source/drain electrode and part of circuit wiring are formed by thermal evaporation of Au. Fig2 shows organic buskeeper circuit on flexible polyimide film.

Measurement

Appling operation voltage of 2V between common V_{DD} and GND pad, we measured the voltages at output pad connected to each SRAM circuits. All measurement was carried out in the atmospheric air.

3. Result and discussion

Buskeeper PUF characteristics

At first, we divided buskeeper chip with 90 SRAM circuits to 4 part as 4 imaginary chips. Each chip contains 21 or 24 SRAMs. Appling operation voltage, we measured output voltage on output terminal. Output voltage of 2-V operated buskeeper PUF theoretically shows 0 V (in "Low" state) and 2 V (in "High" state). We set threshold voltage to 1 V, and binarized output value. Result of all output voltage in buskeeper PUF is shown in Fig3. It shows there could be spatial effect, slightly in longitudinal direction.

In the next step, we evaluate bit error rate (BER) of ID generation. We generate PUF ID more than three times on each chip. We consider average of those generated IDs as ideal IDs on each chips, and calculate exclusive disjunction (XOR) between generated ID and this ideal ID. This XOR is named inter-PUF Hamming distance (HD) corresponding to BER. Histgram of inter-PUF HD is shown in Fig4. Average of inter-PUF HD is 2 bit (9.5% of 21 bits). From this result, it can be said that our buskeeper PUF stably generates ID. We also check uniqueness of buskeeper PUF. We make XOR from two ideal chip IDs. In this study, combination of two chip over all 4 chips are six. This XOR is called inter-PUF Hamming distance which indicates uniqueness of chip IDs. Histogram of inter-PUF Hamming distance is also shown in Fig4 as red bars. Although ideal average of inter-PUF HD becomes 50% of total bits, inter-PUF HD on our buskeeper PUF is 7.3bit. It is about 35% of 21 bit. Inter and intra PUF HD indicate we manage to distinguish each PUF with allowable error rate of 20 %.

4. Conclusion

In this study, we fabricated buskeeper PUF on flexible substrate, and evaluated its operation stability and uniqueness among generated IDs. As a result, average of BER is 9.5%. On the other hand, average of inter-PUF HD among 4 PUF chips was 35%, it is still higher than bit error rate. This result implies that our buskeeper PUF on flexible substrate can be distinguishable from each IDs.

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