Design of Aging-Robust Clonable PUF Using an Insulator-Based ReRAM for Organic Circuits

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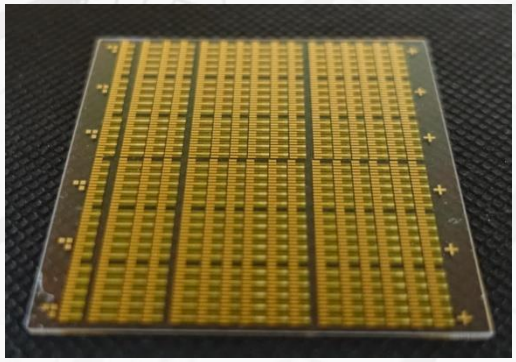
Outline

- **Background**
  - **Organic Thin-Film Transistors and PUFs**
- Proposed PUF
- Evaluations
- Conclusion

Low-Voltage Organic Thin-Film Transistor (OTFT)

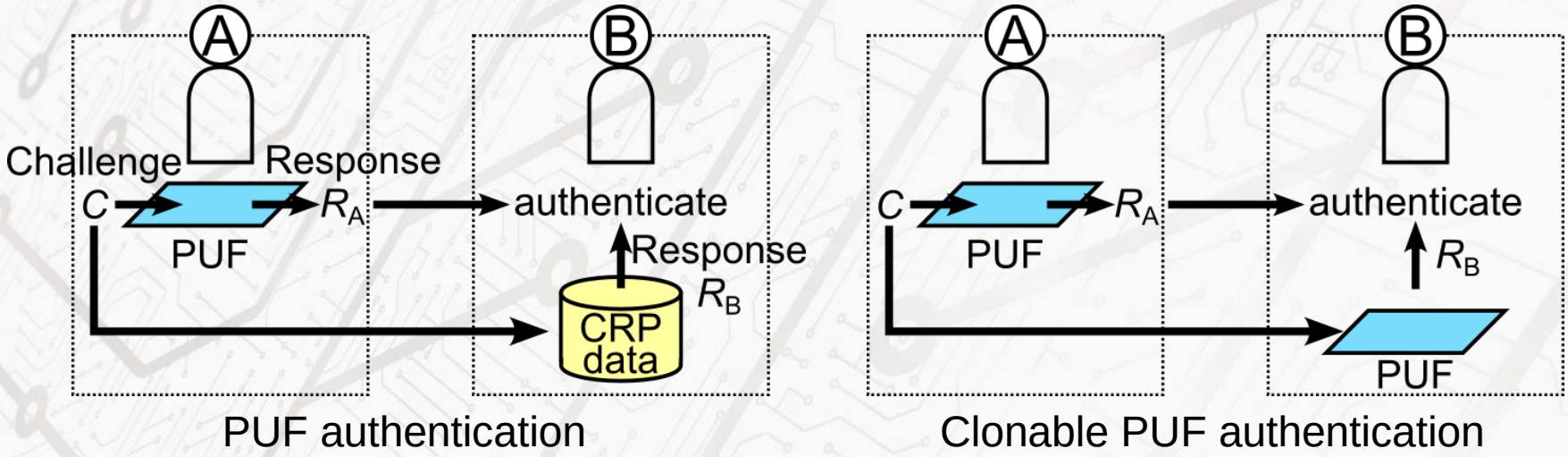
- Promising device for flexible circuits
  - Film or paper substrates are available owing to low temperature processes.



OTFTs on a glass substrate

  - Biosensor systems, artificial skin, … process sensitive personal data.
    - To prevent the use of counterfeit chips and data theft, **<u>an authentication circuit will be essential.</u>**

Physically unclonable function (PUF)



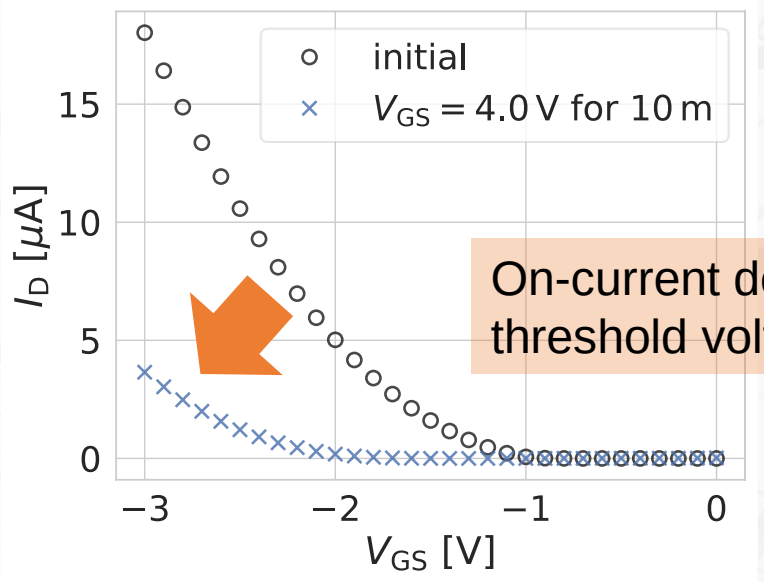
- Authentication circuit

  using physical variability of transistor characteristics

  - **Stable device characteristics are needed**
  - Especially, clonable PUF (CPUF) provides

    authentication without the CRP database.

OTFT Characteristic Degradation in PUFs



I_D-V_{GS} characteristic degradation in a p-type OTFT due to bias voltage application.

- OTFT characteristics degrade rapidly.
  - **PUF responses change due to the degradation.**

Ex) Delay-increase in ring oscillator PUF and

V_{th}-shift in current mirror PUF cause errors.

Objectives of the Proposed PUF

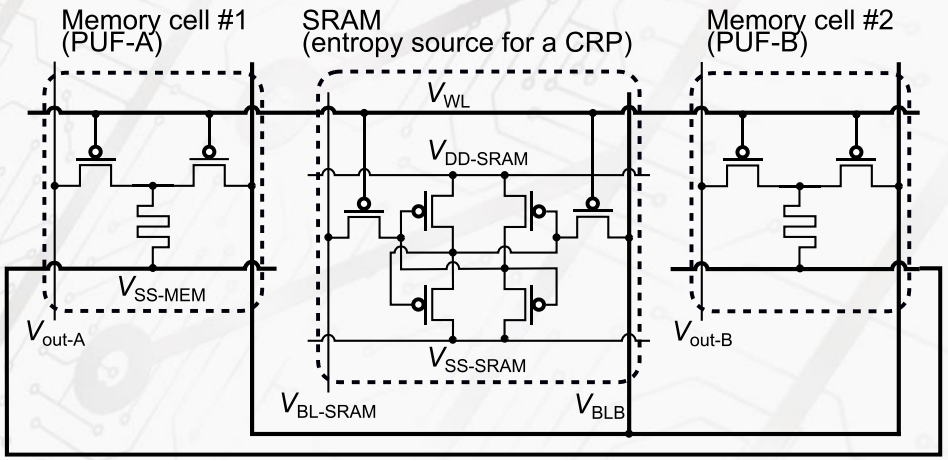
- Store the CRPs within the novel ReRAM devices.
  - **Low fabrication cost**:
    - Manufacturable through the OTFT fabrication process without any cost overhead.
  - **Robustness**:
    - Independent on the OTFT characteristic degradation.
  - **CPUF operation**:
    - The CRPs are duplicatable only during manufacturing.

Outline

- Background
- **Proposed PUF**
  - **Circuit Schematics, Device Structures, and Circuit Operations**
- Evaluations
- Conclusion

The Circuit Structure of the Proposed PUF

- CRPs are generated by the SRAM and written to the ReRAMs during manufacturing.



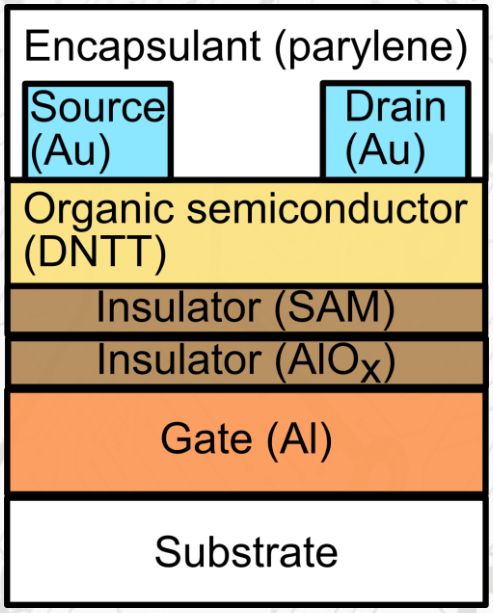
Circuit schematic

  - A novel ReRAM is used for storing CRPs.

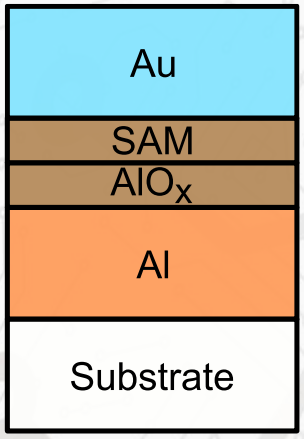
- **<u>Pseudo-CMOS logic is adopted in the SRAM.</u>**
  - p-types are exclusively used due to unstable characteristics of n-types.

Device Structures

- The OTFTs and the proposed ReRAMs share common metal and metal-oxide layer stacks
  - **Manufacturable in the common process with OTFTs**



Bottom-gate top-contact OTFT



The proposed ReRAM

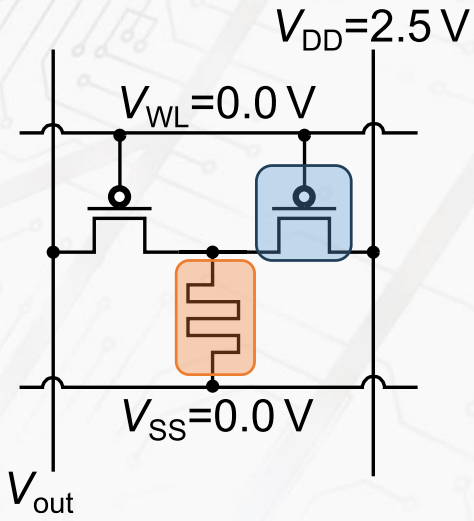
- Common structure to the insulator of OTFTs
- Initially exhibits high resistance ~1 GΩ
- Decreases resistance to ~40 Ω after write operation (antifused)

→**Memory is realized through the two resistance values.**

Read Operation of the Proposed PUF

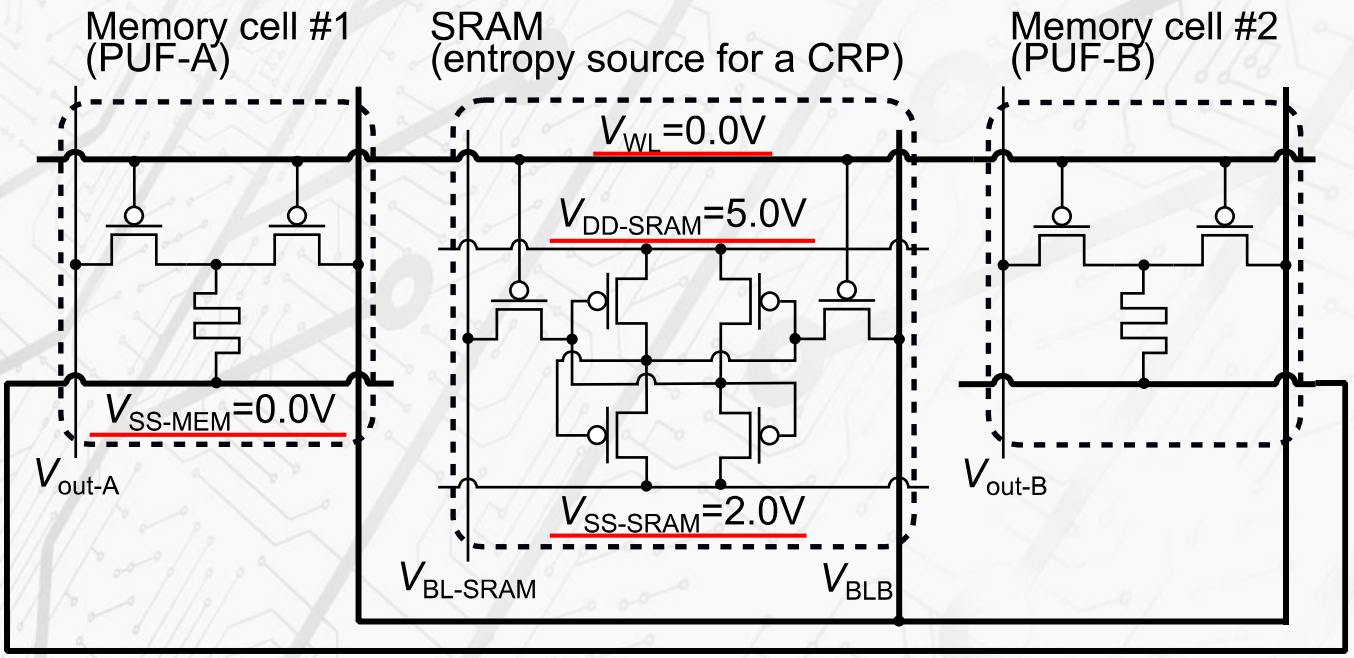
- Voltages are applied as shown in the right figure:
  - V_{out} is obtained by the impedance ratio between the highlighted devices.
  - The ReRAM exhibits 1 GΩ or 40 Ω, while the OTFT on-resistance is about 1 MΩ.

  →**V_{out}=V_{DD} (if R_{ReRAM}=1 GΩ, not antifused); otherwise, V_{out}=V_{SS}.**



Read operation of the proposed PUF

Write Operation of the Proposed PUF



Write operation of the proposed PUF

- **The SRAM outputs 5.0 V or 2.0 V.**
  - **Only high voltage 5 V antifuses the ReRAM.**
- After writing, the SRAM will be discarded.

Outline

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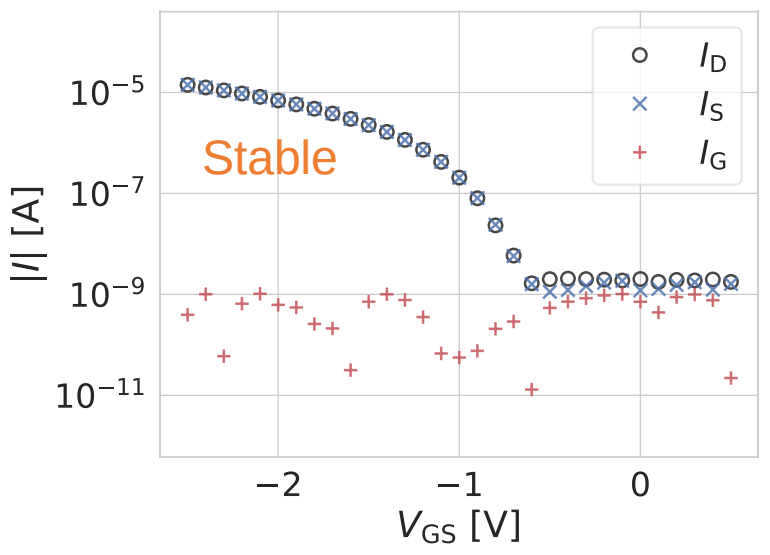
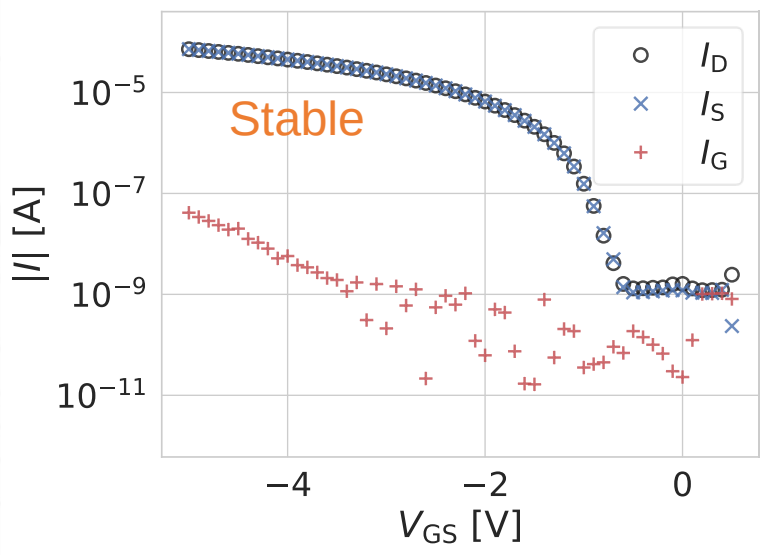
- Proposed PUF
- **Evaluations**
  - **Device Characteristics, Performance of SRAMs as an Entropy Source, and PUF Cell Stability**
- Conclusion

OTFT Characteristics in the Write Operation



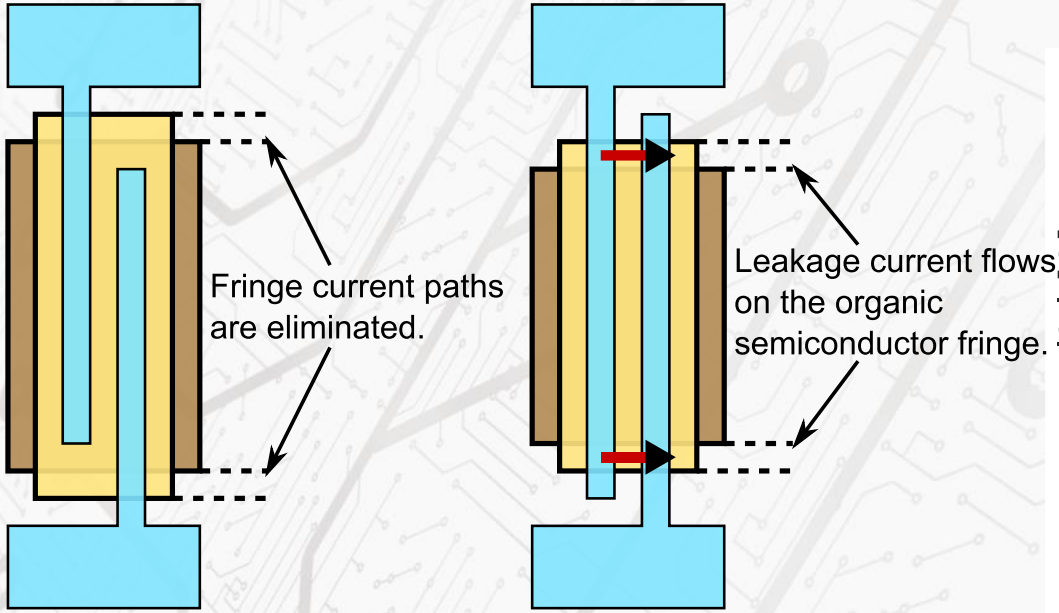
-2.5 V≤V_{GS}≤0.5 V, equal to V_{GS} during the read operation



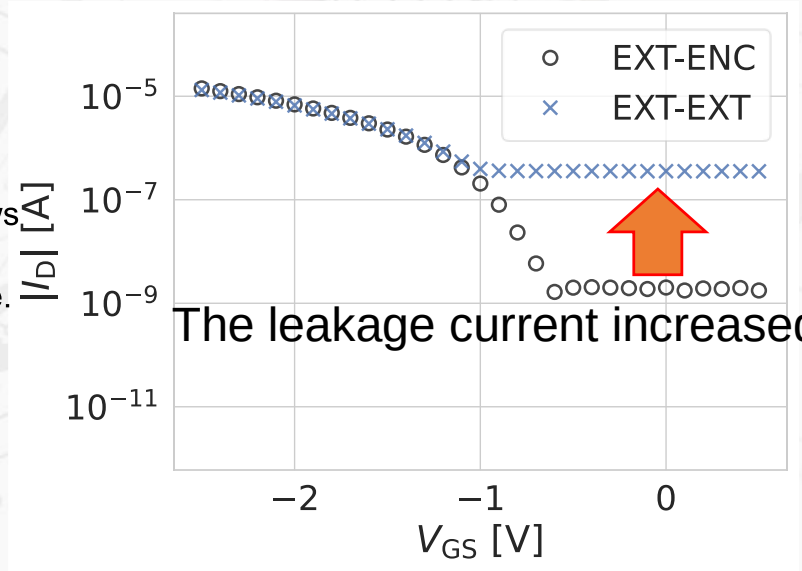
-5.0 V≤V_{GS}≤0.5 V, equal to V_{GS} during the write operation

- The OTFT can operate without an insulator antifuse even under the write operation.
  - **Read and write operations are feasible.**

OTFT Characteristics for the Pseudo-CMOS



EXT-ENC layout　　EXT-EXT layout

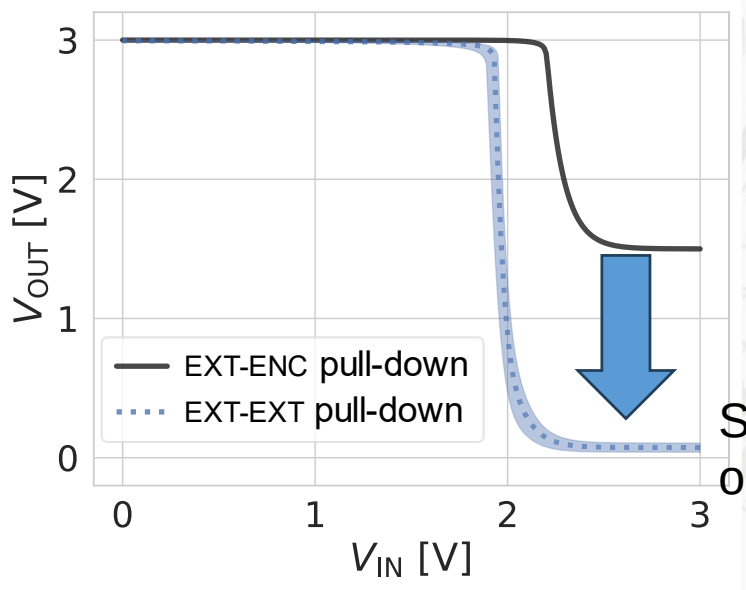


I_D-V_{GS} curves measured in the EXT-ENC and EXT-EXT layout OTFTs.

- **The EXT-EXT layout is used in the pull-down networks.**
  - The large leakage current stabilizes the pull-down output.
- The EXT-ENC layout is suitable for the other parts of circuits.

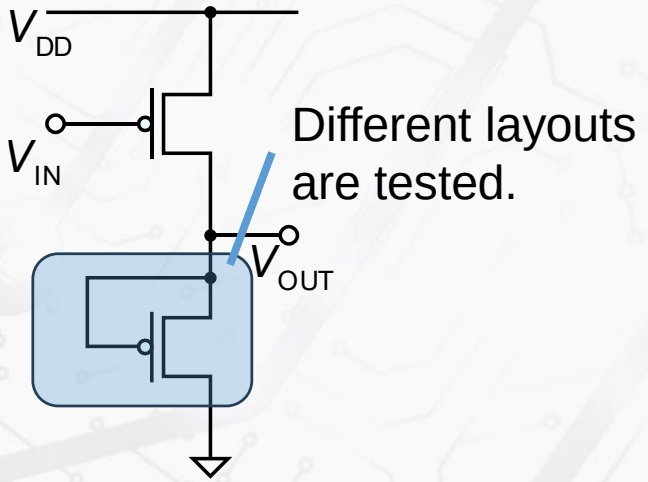
Operation of the Pseudo-CMOS NOT Gate

- **Pseudo-CMOS NOT gates with two pull-down OTFT layouts are compared.**



Transfer curves.

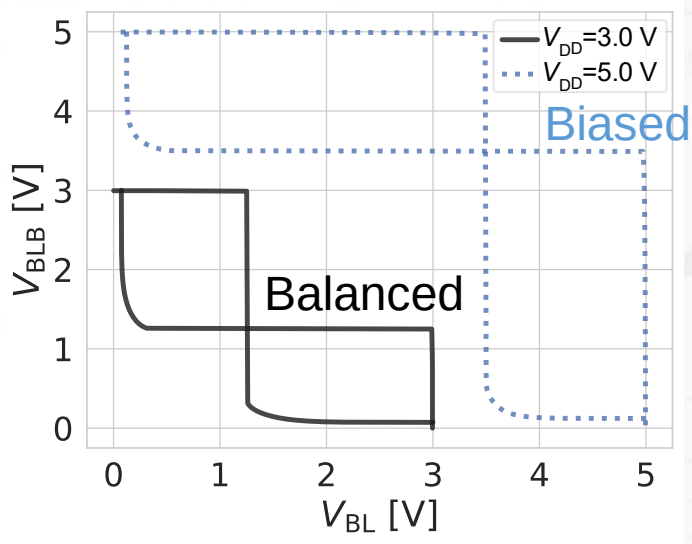
Stable V_{OUT} is obtained.



Schematic of pseudo-CMOS NOT gate.

- The EXT-EXT layout provides stable pull-down V_{out}.

Operation of the Pseudo-CMOS SRAM Cell

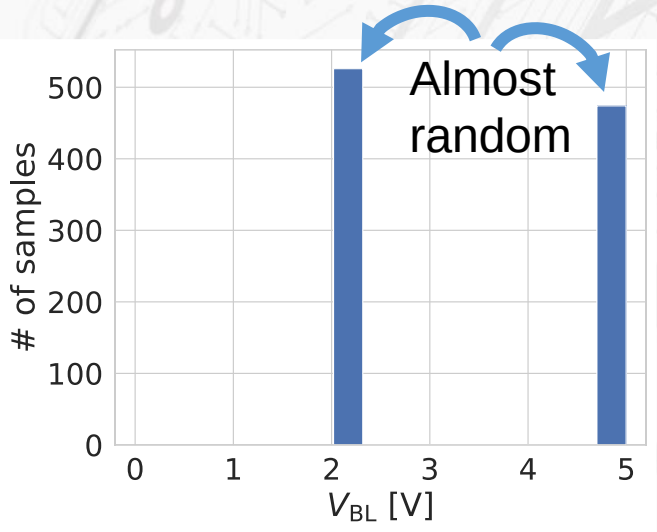


Butterfly curves of a SRAM with different V_{DD} values.

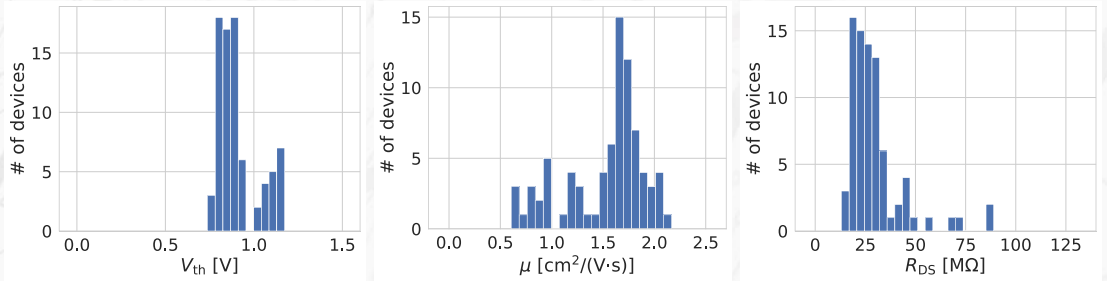
- **<u>V_{DD}≈3.0 V provides a balanced butterfly curve.</u>**
  - High V_{DD} induces a biased entropy source.

→(V_{DD}, V_{SS})=(5.0 V, 2.0 V) is applied in SRAMs, while V_{SS} in memory cells is set to 0.0 V.

Pseudo-CMOS SRAM as an Entropy Source



SRAM output histogram
with sample size 1000.



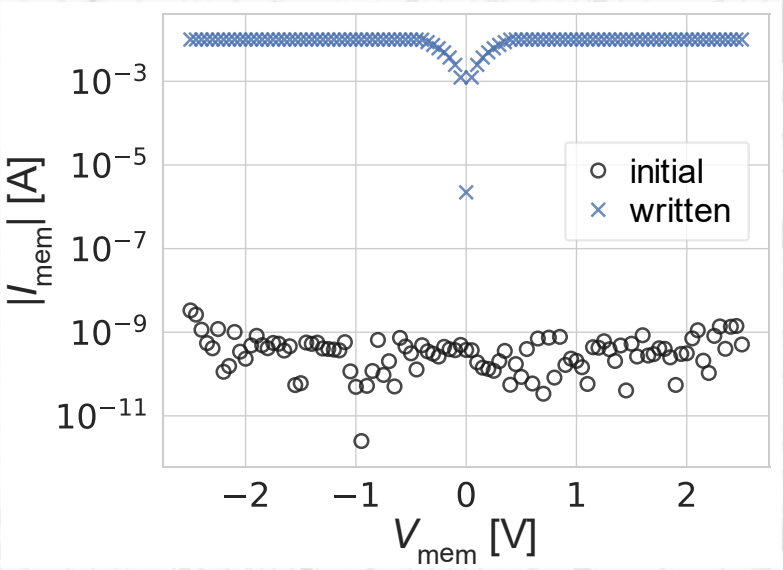
Measured device variability
considered in the simulations.

- Circuit simulations indicate that
  - **SRAMs can generate random responses in the PUF**

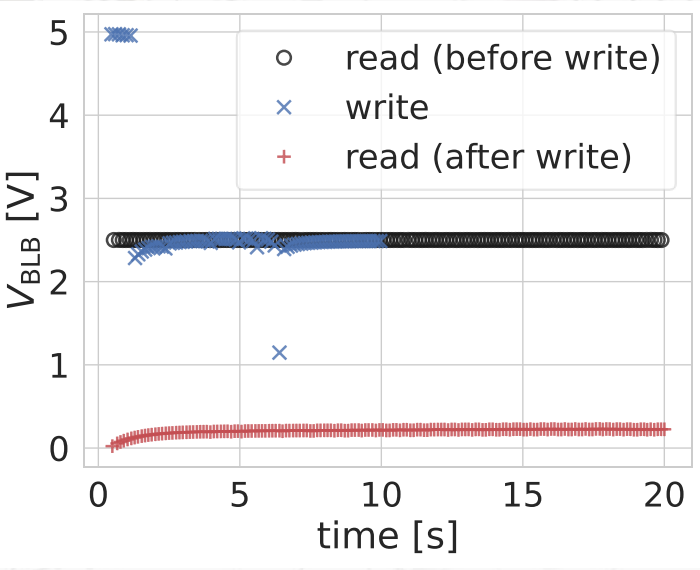
    as demonstrated in existing works [A-C].

[A] J. Guajardo, et al., *in Proc. CHES*, pp. 63—80, 2007.
[B] S. Pandey, et al., *in Proc. ATS*, pp. 55—60, 2016.
[C] A. Vijayakumar, et al., *J. Low Power Electron. Appl.*, 7 (1), p. 2, 2017.

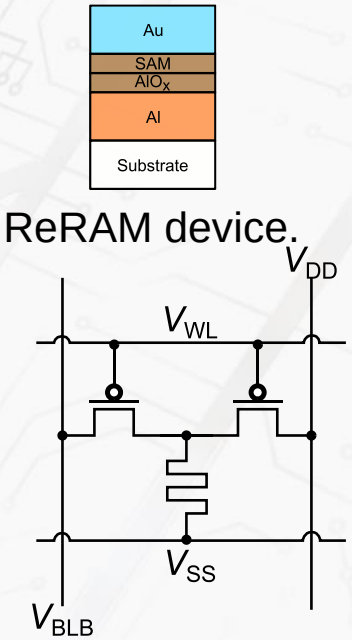
ReRAM Device Characteristics



Measured *I-V* characteristics of a ReRAM device.



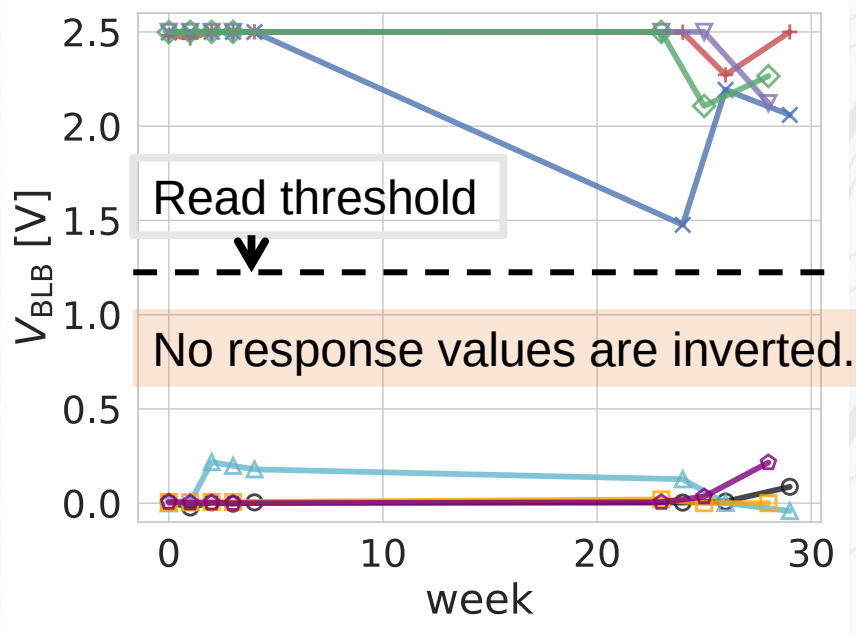
Measured CPUF read voltages using a ReRAM device.



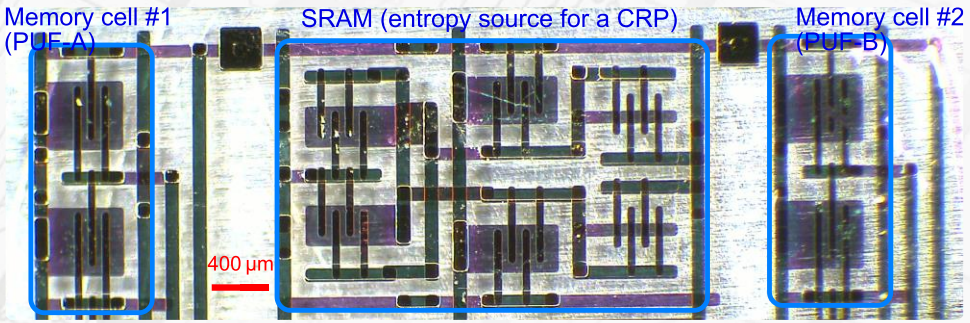
Schematic of a CPUF cell.

- The ReRAM provides **high 0/1 resistance ratio.**
  - ~1 GΩ at “0” logic; ~40 Ω at “1” logic
- **Write and read operations are realized.**

CPUF Cell stability



Measured CPUF output voltages for 28 weeks.



Microphotograph

- **The CPUF cells can store the response data for half a year.**

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- **Conclusion**

Conclusion

- OTFT-based PUF is proposed.
  - Using the proposed ReRAM realizes

    CPUF operation and robust response storing

    without additional fabrication cost overhead.
- The evaluation results show that
  - Devices, and circuit components can work

    under CPUF operations,
  - **The proposed PUF can operate at least for half a year.**