Reconfigurable physically unclonable functions based on nanoscale voltage-controlled magnetic tunnel junctions

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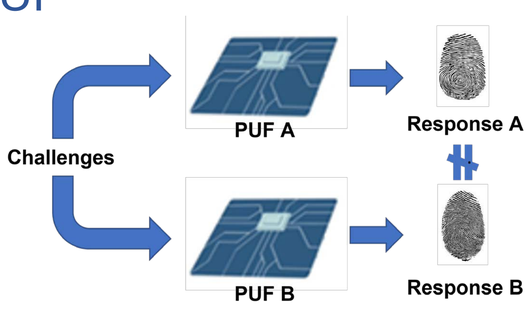
Abstract

Physically unclonable functions (PUFs) have emerged to overcome the shortcomings of conventional software-based cryptographic technology. Existing PUFs exploit manufacturing variations, which results in a static challenge-response behavior and present a long-term security risk. Here we show a **reconfigurable PUF** based on **nanoscale magnetic tunnel junction (MTJ) arrays** that uses stochastic dynamics induced by **voltage-controlled magnetic anisotropy (VCMA).** A total of 100 PUF instances were implemented using **10 ns voltage pulses** on a single chip with a **10×10 MTJ array**. All PUF instances showed **entropy close to 1**, **inter-Hamming distance close to 50%,** and **no bit errors in 10^4 repeated readout measurements**.

Background

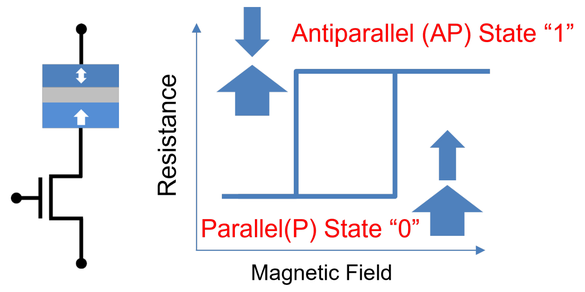
What is a "PUF"

A PUF is an "electronic fingerprint" that provides certain outputs (responses) with respect to certain inputs (challenges), where the challenge-response pairs (CRPs) are unpredictable and unique to each particular device.



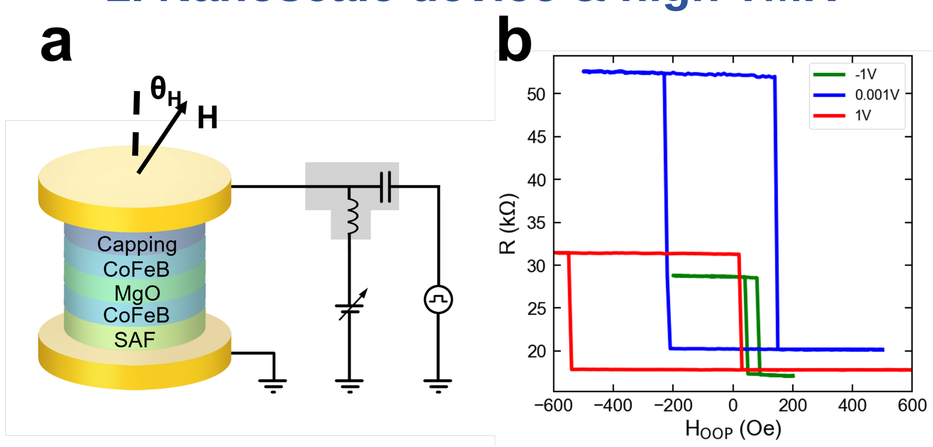
Device schematic

- Readout via tunneling magnetoresistance (TMR)
- $TMR = \frac{R_{AP}-R_P}{R_P}$
- Reconfigure via VCMA-induced precession

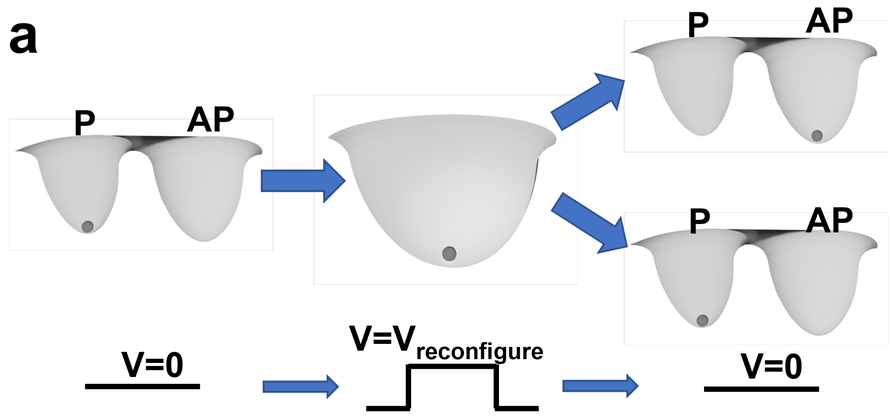


Results

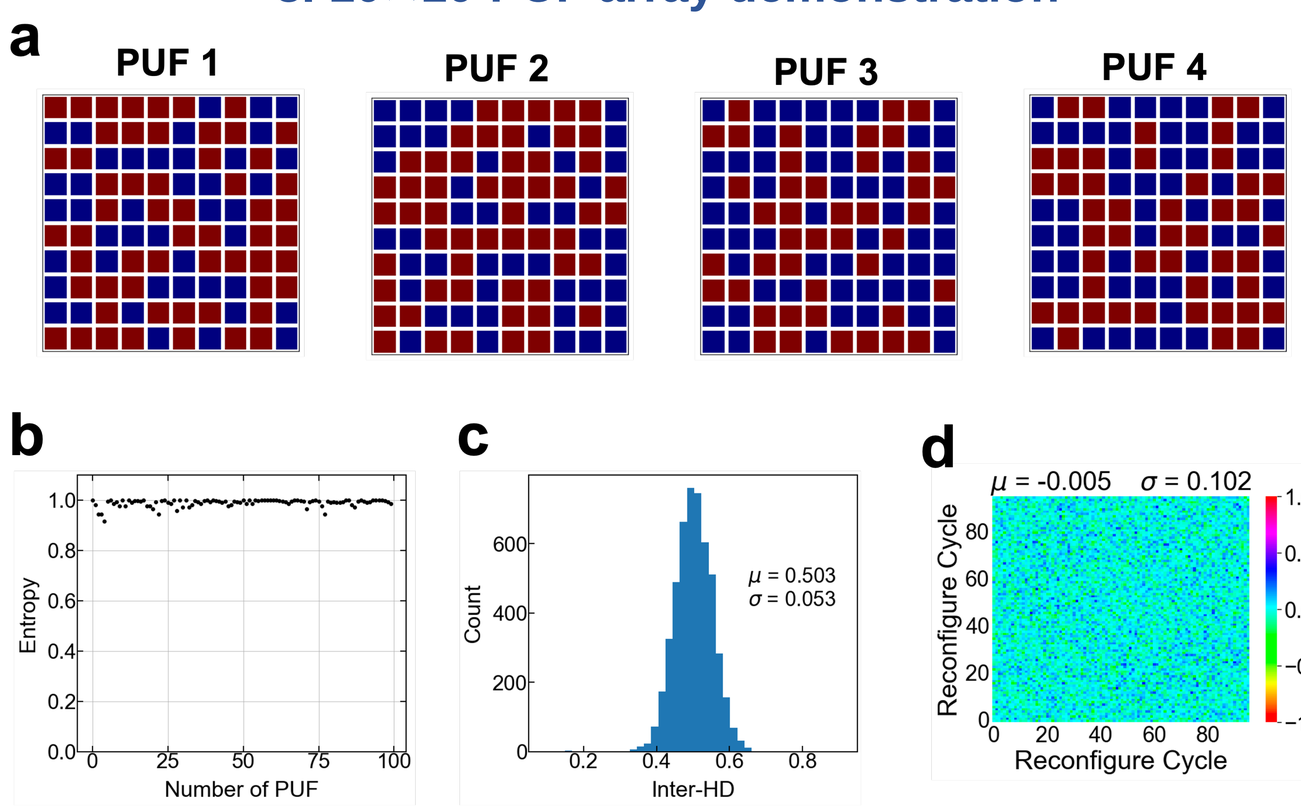
1. Nanoscale device & high TMR



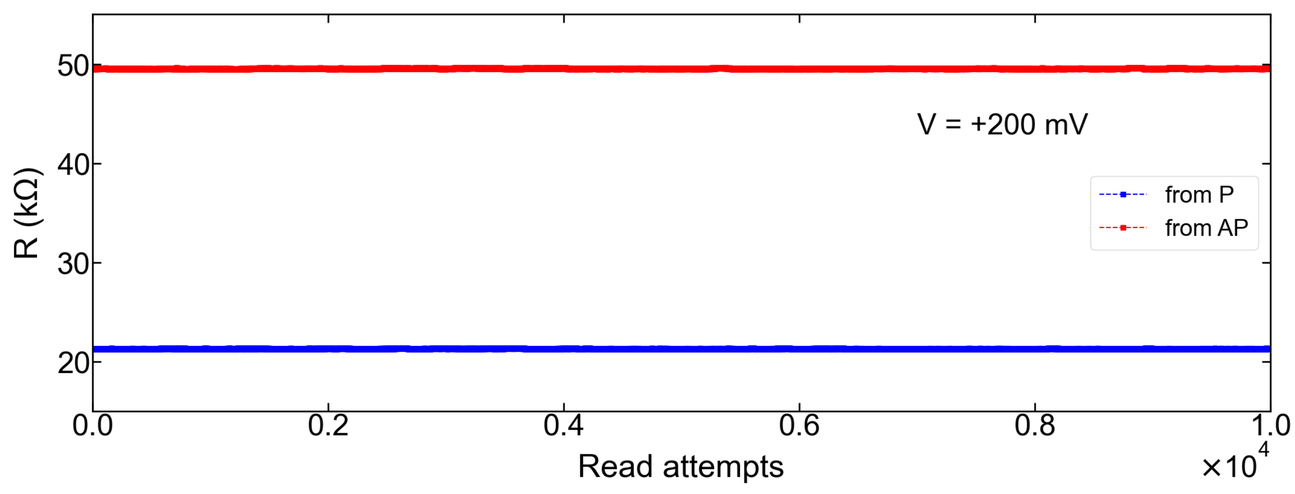
2. Reconfiguration via VCMA



3. 10×10 PUF array demonstration



4. No bit error in 10^4 readouts



For more details, see:

- **Y. Shao et al., "Sub-volt switching of nanoscale voltage-controlled perpendicular magnetic tunnel junctions", Communications Materials 3, 87 (2022).**
- **Y. Shao et al., "Reconfigurable Physically Unclonable Functions Based on Nanoscale Voltage-Controlled Magnetic Tunnel Junctions. ", Advanced Electronic Materials (2023): 2300195.**

References

[1] Pappu, R.; Recht, B.; Taylor, J.; Gershenfeld, N., Physical one-way functions. Science 2002, 297, 2026-2030.
[2] Herder, C.; Yu, M.-D.; Koushanfar, F.; Devadas, S., Physical unclonable functions and applications: A tutorial. Proceedings of the IEEE 2014, 102, 1126-1141.
[3] Gao, Y.; Al-Sarawi, S. F.; Abbott, D., Physical unclonable functions. Nature Electronics 2020, 3, 81-91.

Conclusions

- **MTJ-based reconfigurable PUF** with effective metrics has been demonstrated
- Reconfiguration realized by voltage pulses as short as **10 ns** using **VCMA**
- PUF constructed with a **10 × 10 perpendicular MTJ array** with **high TMR**
- **Entropy of ~1**, **inter-HD of ~ 50%, correlation coefficient of ~ 0**, and **zero bit-errors in 10^4 repeated readout**
- Reliable and compact solution for hardware authentication in CMOS + spintronics integrated systems.

Acknowledgments

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