2 Internship(s) topic:

Characterization of Static and Dynamic Variability in Memristive Devices

and Evaluation of their Usability as Security Primitives for PUFs and TRNGs

Laboratories involved / Advisors:

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Scientific context and motivation:

With the rapid growth of IoT and embedded devices, the development of low power, high density, high performance SoCs has pushed the embedded memories to their limits and opened the field to the development of emerging memory technologies. The Resistive Random Access Memory (ReRAM) has emerged as a promising choice for embedded memories due to its reduced read/write latency and high CMOS integration capability. Intrinsic properties of Resistive memories (RRAMs) make them suitable for the implementation of basic security primitives such as Physically Unclonable Functions (PUFs) and True Random Number Generators (TRNGs). RRAMs are based on the effect of sudden and important switching in the resistance values of specific materials or devices. They consist one of the most promising non-volatile memory alternatives, especially for being implemented in crossbar architectures [1], which are very good candidates for achieving the smallest memory cell [2]. From a technological standpoint, metal oxides (OxRAM) and phase-change materials (PCRAM) are the most studied materials. The nitrides however, especially silicon nitrides (SiN_x), exhibit competitive resistance switching properties and SiN_X is more resistant to oxygen and metal atoms diffusion [5], guaranteeing a better reliability. Functional SiN-based RRAM devices were recently demonstrated by INN/Demokritos (Greece) for application in neuromorphic and in-memory computing [7], as well as TRNGs [8]. The same group has also shown in [9] that using a thin Silicon-On-Insulator (SOI) film instead of bulk Si substrates as bottom electrode can prove advantageous, thanks to the higher series resistance of the SOI and the self-compliance it provides in current-voltage characteristics. No analytical studies have been yet performed nor published, concerning how the different concentrations of Nitrogen in SiN_x or doping levels in the SOI layer can affect the device noise and mismatch. In particular, the dynamic stability of a resistive memory (cycle-to-cycle variability) [10], as well as its endurance (number of read/write cycles before failure) are tightly correlated to the defective zones in or around the conductive filament, that either pre-exist or are generated during the memory's cycles.

Therefore, the electrical characterization of the SiN-based RRAMs' dynamic behavior is a requirement for the proper evaluation of their performance, as well as their potential use in applications like TRNGs (exploiting their noise behavior / dynamic variability) and PUFs (exploiting their variability). The various defect characterization tools that can be applied in RRAM devices include low-frequency noise (LFN), random telegraph noise (RTN), noise spectroscopy and Discharging Current Transient Spectroscopy (DCTS), alongside with the cycle-to-cycle variability and endurance measurements. Experimental results from last year's internship revealed a true potential, especially for TRNGs, and they need to be further verified and explored.

The 2 interns will work closely together and will also reinforce the collaboration between C. THEODOROU (IMEP-LAHC) and I. VATAJELU (TIMA) in the framework of FMNT, but also between CNRS and the National Center for Scientific Research "DEMOKRITOS" (INN) in Greece, who will provide the samples to study thanks to an on-going International Emerging Action project. A possibility of continuing for a PhD thesis will also be discussed.

Internship objectives

Based on the challenging context described above, this project aims to:

Internship #1

perform electrical characterisation on a considerable number of devices such that the device-to-device static variability can be well described for the correct evaluation of a possible PUF implementation (Physically Unclonable Functions (PUFs) take advantage of the static variability of fabricated devices to generate a signature unique to every fabricated circuit

Internship #2

perform electrical characterisation on individual devices for a considerable number of write/read cycles such that the cycle-to-cycle variability can be well described for the correct evaluation of a possible TRNG implementation. True Random Number Generators (TRNGs) take advantage of the dynamic variability (noise) affecting the device operation to generate random numbers.

Requested competences:

The internship is dealing with an interdisciplinary topic, covering a wide panel of know-hows, from semiconductor device physics to electrical characterization and circuit applications. The candidates must have a good background in electronics or/and semiconductor physics, while experience with experimental measurements and data processing (preferably Python) would be highly appreciated. The candidates are expected to enjoy experimental work and development of adapted protocols. Scientific curiosity and motivation, as well as knowledge of English language, are mandatory qualities in order to take full advantage of the multidisciplinary and international scientific environment of this internship and to gain expertise for their future career.

References

[1] Qiangfei Xia and J. Joshua Yang. "Memristive crossbar arrays for brain-inspired computing." Nature materials 18.4 (2019): 309-323.

[2] Edwards, Arthur H., et al., "Reconfigurable memristive device technologies." Proc. IEEE 103.7 (2015): 1004-1033.

[3] Sparsh Mittal, "A survey of ReRAM-based architectures for processing-in-memory and neural networks." Machine learning and knowledge extraction 1.1 (2019): 75-114.

[4] M. Ueki, et al., "Low-power embedded ReRAM technology for IoT applications." 2015 symposium on VLSI technology (VLSI technology). IEEE, 2015.

[5] N. Vasileiadis, et al., "Understanding the role of defects in Silicon Nitride-based resistive switching memories through oxygen doping." IEEE Trans. on Nanotechnology 20 (2021): 356-364.

[6] S Kim, et al,. "Resistive switching characteristics of Si3N4-based resistive-switching random-access memory cell with tunnel barrier for high density integration and low-power applications", Applied Physics Letters 106 (21), 212106

[7] N. Vasileiadis, et al., "In-Memory-Computing Realization with a Photodiode/Memristor Based Vision Sensor", Materials 2021, 14, 5223

[8] N. Vasileiadis, P. Dimitrakis, V. Ntinas and G. C. Sirakoulis, "True Random Number Generator Based on Multi-State Silicon Nitride Memristor Entropy Sources Combination," 2021 International Conference on Electronics, Information, and Communication (ICEIC)*, 2021, pp. 1-4, doi: 10.1109/ICEIC51217.2021.9369817.*

[9] A. Mavropoulis et al., "Effect of SOI substrate on silicon nitride resistance switching using MIS structure", Solid-State Electronics, Volume 194, 2022

[10] Giuseppe Piccolboni et al.. Investigation of Cycle-to-Cycle Variability in HfO_2-Based OxRAM. IEEE Electron Device Letters, Institute of Electrical and Electronics Engineers, 2016, 37 (6), pp.721-723.