Ultra-Low Power CBRAM with Multilevel Cell Precision for Digital Twins of Engineered Living Materials

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Overview

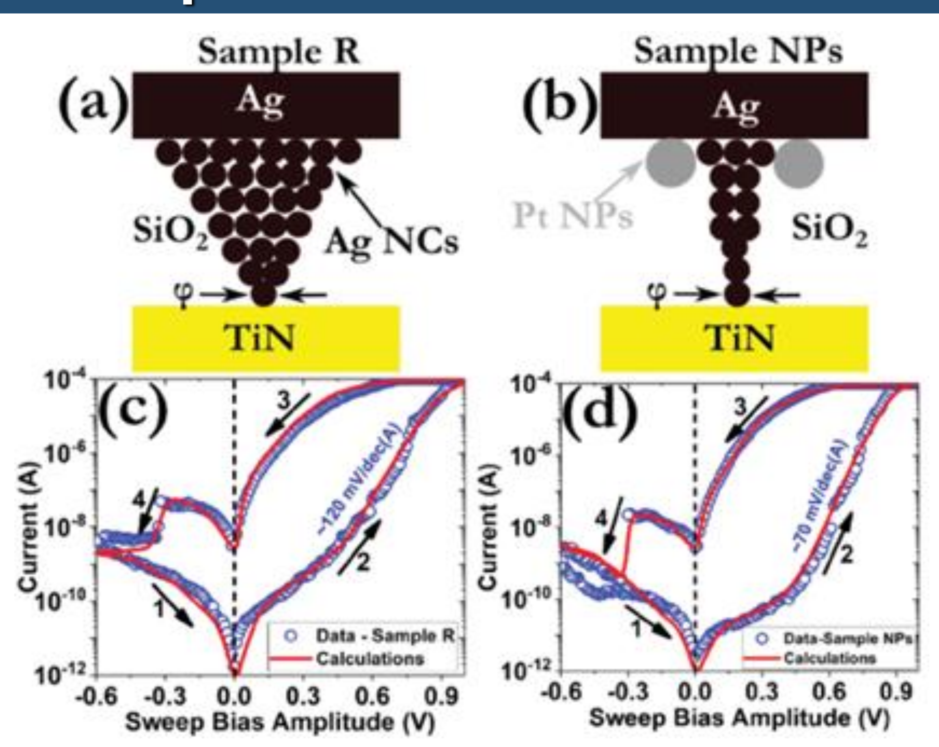
Motivation:

- **Challenges in modern data storage and computing systems** in the context on emerging architectures [1], [2]:
  1. In Memory computing, and non-Von Neumann systems
  2. Which are vital for the emerging field of **Artificial Intelligence**

Our Proposal:

- **A Pt Nanoparticle enhanced CBRAM integrated in an 1T1M scheme.**
  1. **The NP layers act limit the stochasticity of conductive Filament formation**
  2. **Thus, assisted by an adaptive algorithm, 6-bit operation was achieved**

Pt Nanoparticle Enhanced CBRAM



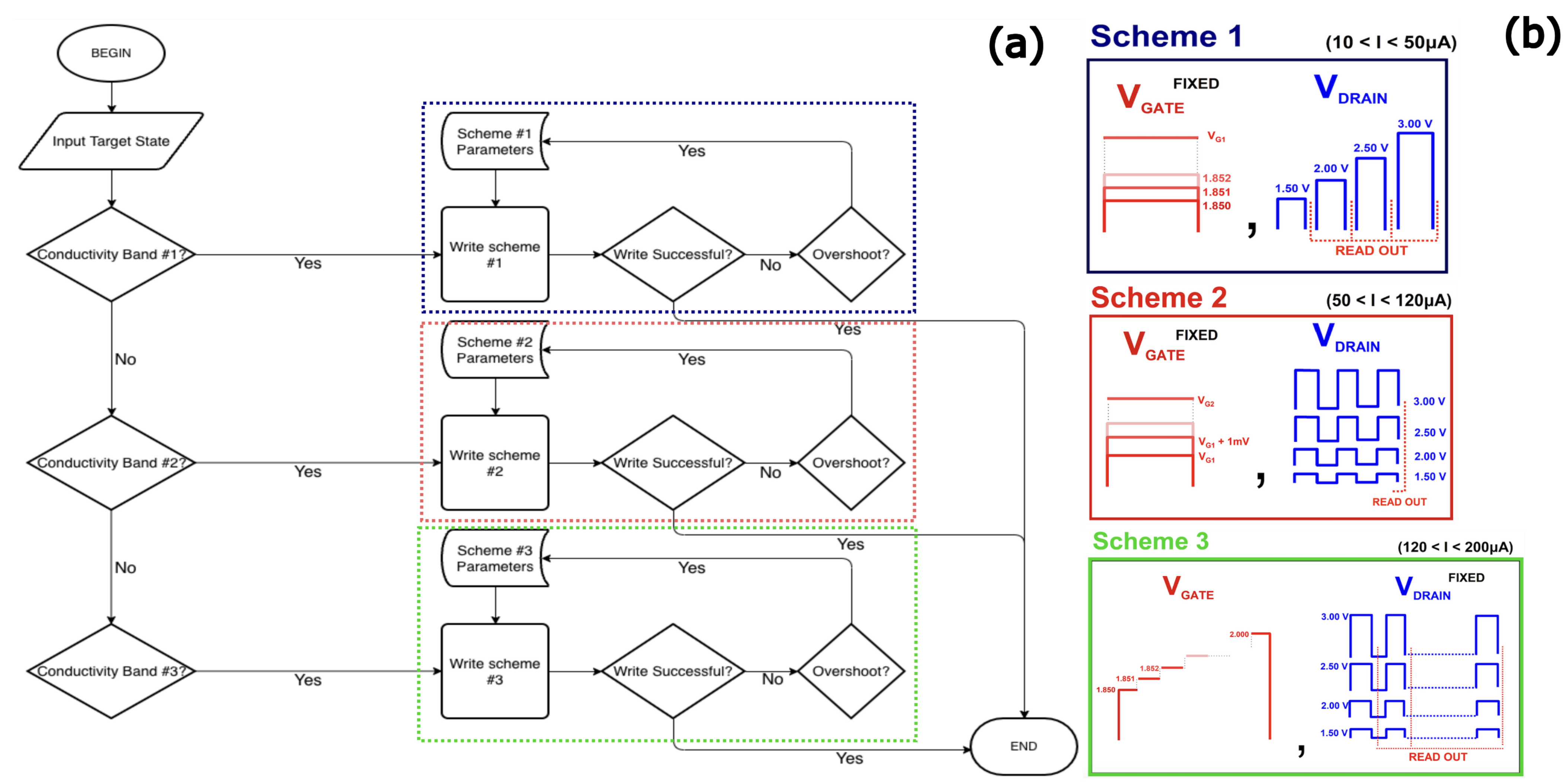
Comparison of device architecture and device performance between a reference Metal-Insulator-Metal CBRAM and the proposed Pt NP enhanced architecture

6-bit Multilevel cell Performance

By leveraging the NC-enhanced CBRAM structure, the research achieved [3]:

- **Up to 6-bit memory precision, a significant improvement over traditional memory technology.**
- **Low energy consumption was maintained, making the technology ideal for applications, such as Internet of Things (IoT) devices and AI accelerators.**
- **A novel adaptive state control algorithm (ASCA) was developed. This algorithm dynamically adjusts the pulse strength and gate bias to achieve precise control over the memory states.**
- **The ASCA facilitates reliable multistate programming and reading, crucial for high-density memory applications.**

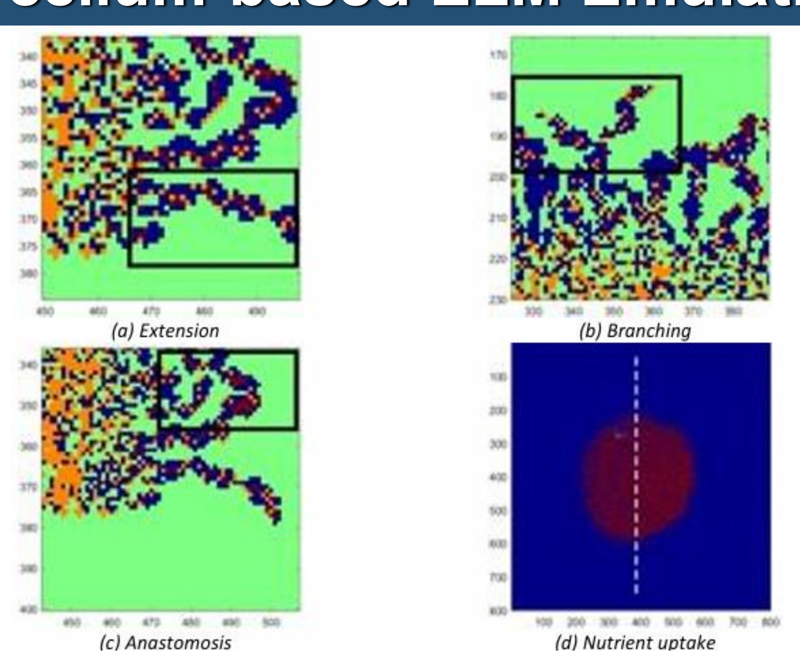
Adaptive State Control Algorithm - ASCA



To optimize the device's multilevel operation, a novel adaptive state control algorithm (ASCA) was developed.

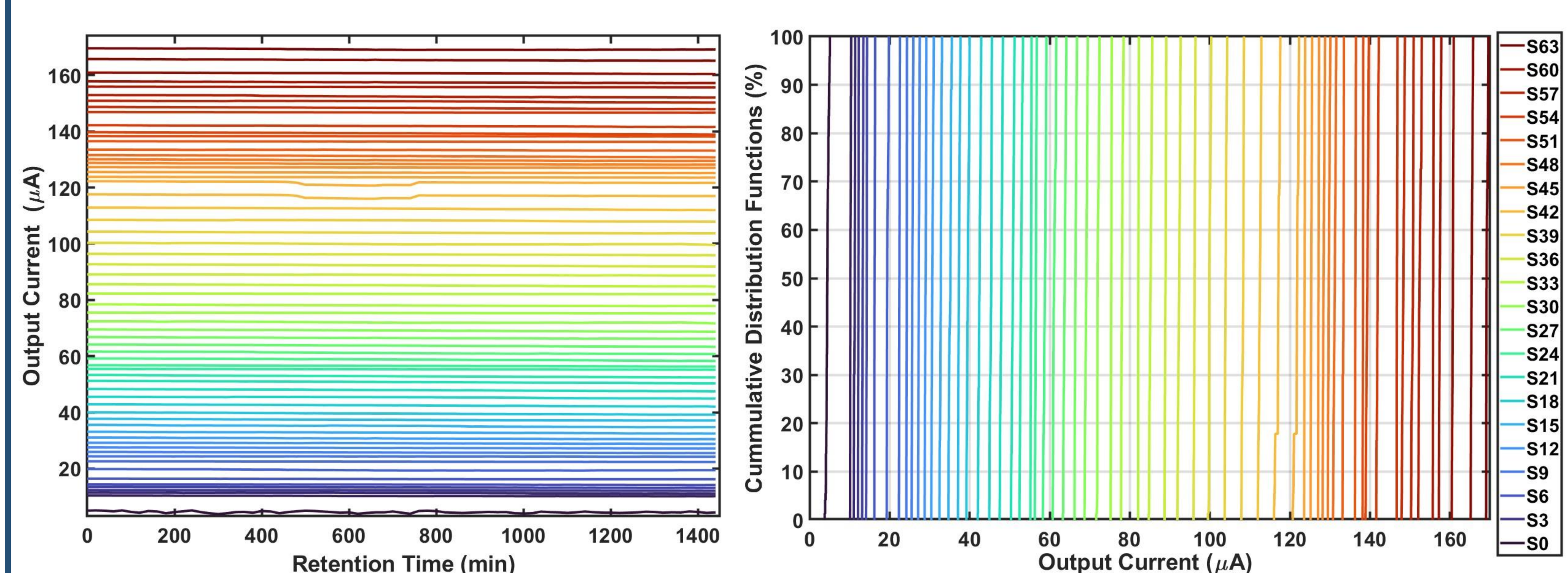
- **ASCA dynamically adjusts the pulse strength and gate bias to achieve precise control over the memory states**
- **The ASCA facilitates reliable multistate programming and reading, crucial for high-density memory applications.**

Mycelium-based ELM Emulation



Utilize the analog and low-power characteristics of CBRAM devices to mimic the biological processes of Engineered Living Materials (ELMs), focusing particularly on a widely studied ELM based on mycelium hyphae. [4]

Memory Retention Measurements and CDF plots



Multibit CBRAMs to develop Digital Twin Prototypes for Engineered Living Materials

- **The enhanced capabilities of a low-power, highly uniform RRAM technology, will be exploited into the development of a Digital Twin Protype (DTP) for simulating the electrical and morphological behaviour of mycelium based ELMs.**
- **By utilising the Pt-NC enhanced devices, such works may benefit substantially in terms of precision, reliability and especially energy efficiency which is highly important to accurately mimic a low-power biological system and being able to deploy the DTP to the same energy constrained environment.**
- **The additional MLC capability in conjunction with the consistent performance offered by employing the ASCA programming scheme, may also enable accurate modelling of the reaction-diffusion processes that govern mycelium growth, paving the way for bioinspired and sustainable material-based computing.**

References

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[4] P. T. Chatzinikolaou, *et al.*, doi:10.1109/NANO61778.2024.10628662

Acknowledgements

This work has been partially supported by the framework of the FUNGATERIA project, which has received funding from the European Union's HORIZON-EIC-2021-PATHFINDER CHALLENGES program under grant agreement No. 101071145.