Magneto-ionic synaptic devices

L. Herrera-Diez

[1]Centre de Nanosciences et de Nanotechnologies, CNRS, Université Paris-Saclay, 91120 Palaiseau, France

*liza.herrera-diez@universite-paris-saclay.fr

The ability to manipulate magnetic properties through ionic motion in ferromagnetic/oxide structures in a non-volatile way, rather than through volatile, purely electronic means, presents exciting opportunities for the development of functionalities like reconfigurable multistate memories and the implementation of cumulative gate effects in spintronics devices. Magneto-ionics takes inspiration from memristor technologies and offers one of the most advanced approaches today for controlling magnetic properties using ionics. Integrating ionic and spintronic technologies offers new degrees of freedom to design neuromorphic hardware with novel magnetic functionalities, alongside the established ionic analogue behavior.

I will present different strategies to develop multistate magneto-ionic memory devices using CoFe alloys. A variety of material combinations and device designs allows to explore the control of nucleation/propagation of a spin-reorientation transition under gate voltage and the exploration of an extended gate-induced oxidation-reduction spectrum to generate multiple stable, electrically detectable magneto-ionic states. I will also demonstrate that magneto-ionic nanodevices can not only function as basic synaptic elements, using their capacity to encode multiple analogue states, but also enable new bioinspired functionalities. We show that in magneto-ionic synaptic elements, synaptic depression can be tuned using a magnetic field, allowing to dynamically control the linearity of the synaptic weight update. This functionality is reminiscent of neuromodulation, observed in biological systems, and neural network simulations reveal that a magnetically induced enhancement in weight-update linearity improves learning accuracy across a wide range of learning rates.

These findings highlight the versatility and promise of magneto-ionic devices for developing multifunctional synaptic elements for neuromorphic hardware.

References

[1] G. Bernard, K. Cottart, M-A. Syskaki, V. Por´ee, A. Resta, A. Nicolaou, A. Durnez, S. Ono, A. Mora Hernandez, J. Langer, D. Querlioz and L. Herrera Diez, ‘Dynamic Control of Weight-Update Linearity in Magneto-Ionic Synapses’ Nano Letters 25, 4, 1443–1450 (2025).

[2] G. Bernard, X. Lafosse, C. Tataru, M.-A. Syskaki, A. Durnez, F. Mahut, D. Ravelosona, J. Langer and L. Herrera Diez, ‘Magneto-ionic Control of a Propagating Spin Reorientation Transition’ Nano Letters 25, 32, 12241–12247 (2025).

[3] I. Benguettat-El Mokhtari, R. Pachat, V. Porée, A. Lamperti, Y. Roussigné, M.-A. Syskaki, J. Wrona, G. Bernard, A. Cataldo, A. Resta, A. Nicolaou, S. Ono, J. Langer, D. Ravelosona, M. Belmeguenai, A. Solignac, L. Herrera Diez, ‘Exploring the full magneto-ionic oxidation spectrum in Pt/CoFeB/HfO_2’, Appl. Phys. Lett. 126, 232402 (2025).

[4] T. da Camara Santa Clara Gomes, T. Bhatnagar-Schöffmann, S. Krishnia, Y. Sassi, D. Sanz-Hernandez, N. Reyren, M-B. Martin, F. Brunnett, S. Collin, F. Godel, S. Ono, D. Querlioz, D. Ravelosona, V. Cros, J. Grollier, P. Seneor, L. Herrera Diez, ‘Control of the magnetic anisotropy in multi-repeat Pt/Co/Al heterostructures using magneto-ionic gating’ Phys. Rev. Applied, 21, 024010 (2024).

[5] T. Bhatnagar-Schöffmann, P. Schöffmann, A. Resta, A. Lamperti, G. Bernard, A. Kovacs, L. Largeau, A. Durnez, A. Harouri, X. Laffosse, D. Ourdani, M.-A. Syskaki, Y. Roussign´e, S. Ono, R. E. Dunin-Borkowski, J. Langer, D. Ravelosona, M. Belmeguenai, A. Solignac and L. Herrera Diez, ‘Non-oxidative mechanism in oxygen-based magneto-ionics’ Adv. Mater. Interfaces 2300955, (2024).