ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE,TAKES YOU FAR

XXXIII Cycle

Design and modeling of spintronic devices based on magnetic skyrmions

Luca Gnoli

Supervisor: Prof. Mariagrazia Graziano

Research context and motivation

Spintronics

Spintronics is a research filed that technologies that take advantage of the **electron and molecular spin to encode and transmit information**. This added degree of freedom open the door to device of new conception.

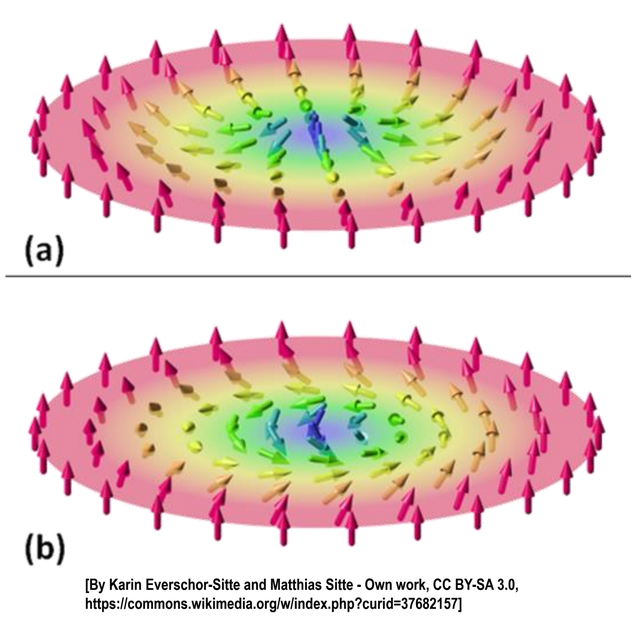
Being the magnetization strictly linked with spin, many spintronic devices take advantage of magnetic ordering to **retain their state** even for very long periods of time without the need of any refresh operation.

Skyrmions

Magnetic skyrmions are swirl magnetic configurations which present a **core with opposite polarity with respect to the bulk magnetization.**

Such magnetic textures are stabilized by bulk or interface Dzyaloshinskii Moriya interactions (DMI).

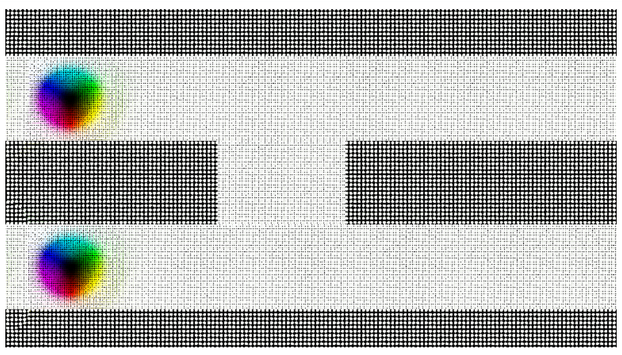
The materials that can host such configuration are ferromagnets with lack of inversion symmetry.



[By Karin Everschor-Sitte and Matthias Sitte - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=37682157]

Magnetic skyrmions were proposed as information carriers encoding the information in their presence or absence recalling the concepts of linear domain walls in racetrack memories (Perkin 2008, IBM). The advantages shown by magnetic skyrmions are a higher stability, lower sensitivity to defects on the string and a higher velocity with the same current input.

Addressed research questions/problems



Skyrmion Cascade Logic Gate

Micromagnetic Simulation Computational Cost:
256 x 128 x 2 = **65536 Cells**
Solution of 65536 ordinary differential equations per time step

Micromagnetic simulation of Skyrmions magnetic textures are extensively used to simulate, prior to experimental verification, the functionality of magnetic devices. Simulations use finite element approach to the structure. LLG equation is solved for every element of the mesh. Graphical processing units (GPU) are often employed to reduce drastically the simulation time. Nevertheless simulation are **extremely expensive in terms of computational effort and consequently simulation time.**

Design space exploration and device tuning require a faster mean to simulate and tune devices based on skyrmions dynamics.

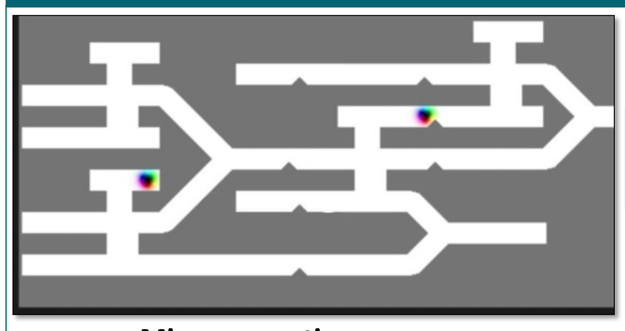
Thiele developed in 1971 a particle-like model for magnetic hard bubbles focusing the attention on translational modes of such structures, the same approach is applicable to skyrmions assuming the rigidity of the magnetic texture.

$$\mathbf{G} \times (\mathbf{v}^{(s)} - \mathbf{v}^{(d)}) + \mathcal{D}(\beta \mathbf{v}^{(s)} - \alpha \mathbf{v}^{(d)}) - \nabla V(\mathbf{r}) = \mathbf{0}$$

Submitted and published works

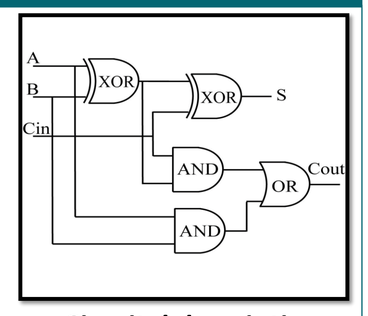
- Ferrara, A; Garlando, U; Gnoli, L; Santoro, G; Zamboni, M - 3D design of a pNML random access memory – 13th Conference on Ph.D . Research in Microelectronics and Electronics (PRIME) 2017
- Ardesi, Y; Gnoli, L; Graziano, M; Piccinini, G - Bistable Propagation of Monostable Molecules in Molecular Field-Coupled Nanocomputing – 15th Conference on Ph.D . Research in Microelectronics and Electronics (PRIME) 2019
- Gnoli, L; Vacca, M; Graziano, M; Mathew, J; Ottavi,M er al. – Fault Tolerant Photovoltaic Array: a repair circuit based on memristor sensing – IEEE International Symosyum onDefect and Fault Tolerance in VLSI and Nanotechnology Systems (DFT) 2019

Novel contributions



Micromagnetic

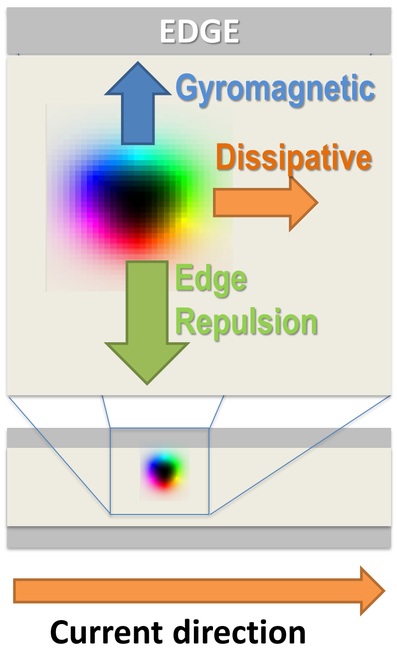
Proposed model



Circuital description

The research has the following aims:

- **adapt the model based on Thiele formulation** to fit micromagnetic simulation of **confined Skyrmion devices** and eventually experimental data.
- evaluate **performance parameters** of confined Skyrmion-based magnetic devices
- integrate the model with higher level hardware description languages (e.g VHDL)



Model description:

Skyrmion is modeled as a particle subjected to **forces**:

- **Gyromagnetic force** is linked only to skyrmion core.
- **Dissipative force** depends on the skyrmion shape.
- **Edge repulsion** depends on the nanotrack shape.
- **Pinning forces** comes from pinning potentials that are derived from anisotropy field imperfections.
- **Repulsion** from other skyrmions comes from the magnetic interactions between two skyrmions

Adopted methodologies

Micromagnetic Simulations → Model development and validation → Embedding in hardware description language

- Simulation of devices with **micromagnetic approach** to give to the model a reference. Simulations performed with Mumax3, GPU accelerated micromagnetic simulator.
- Model of **confinement potential** based on nanotrack shape
- Integration of **pinning potential models**
- Complete **model validation** with reference micromagnetic simulations
- Embedding of the model in **Hardware Description language** (e.g. VHDL) of selected set of skyrmions logic gates.

Future work

- Being the **Spin Hall effect** a very efficient mean for skyrmion movement, it will be important to add such effect to the proposed model.
- Proceed to the verification and modelling of more complex structures to understand the **architectural limits of application of Skyrmions to logic and memory**.
- Explore the possibility to **join skyrmions devices with other magnetic technologies** to overcome technological limitations of skyrmions especially poor integration and low operational speed

List of attended classes

- 01SGURV– Intellectual property Rights (March 2018, 30)
- 01LDVRU – Magnetismo nei material e misure magnetiche (June 2019, 20)
- 01TCPRV – Nano and molecular electronics (July 2019, 40)
- 01SFURV – Programmazione scientifica avanzata in Matlab (March 2018, 20)
- 01RONKG – Python in the Lab (March 2019, 20)
- 01QSCIU – Reconfigurable computing (June 2018, 20)
- NA – Innovation for change (June 2018, 30)

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering