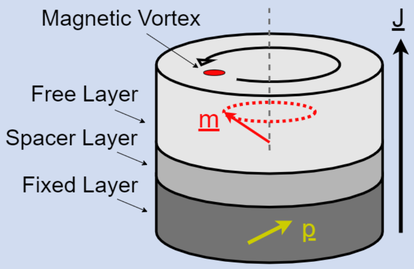
Dipolar Coupling Control of Vortex Based Spin Torque Nano-Oscillators

1. Introduction

Neuromorphic Computing

- Neuromorphic computing draws inspiration from the brain to achieve vast parallelism in computation
- Memory and calculation are housed in the same structure
- Such implementation has many benefits, such as low power consumption [1]

Spin Torque Nano-Oscillators (STNO)



- STNOs are made up of ferro- and non-magnetic disks.
- Current is spin polarised by the fixed layer
- This induces a spin torque in the free layer

Figure 1. Structure of an STNO showing the different layers present and the gyrotropic oscillation mode that was reached, where **m** is the magnetisation of free layer, **p** is the polarisation of fixed layer

- The frequency of the oscillation is dependent on geometry and driving current
- STNOs frequencies synchronise to external sources
- They can synchronise to each other through spinwaves, microwaves and dipolar coupling [2]

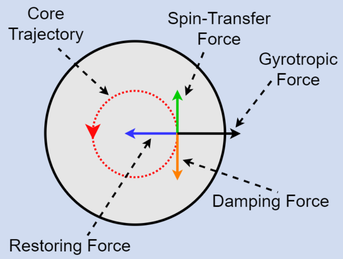


Figure 2 shows the forces acting on the vortex core as it carries out auto oscillation

2. Method

- Micromagnetics is primarily described by the Landau-Lifshitz-Gilbert equation
- Micromagnetic simulations were carried out using MuMax3 [3]. Various geometries of STNO nano-pillars were simulated to understand and control their dipolar coupling

- Nano-disks of ~150nm, ~10nm thick, are bistable in both vortex and uniform states [4]
- Work here was carried out to understand the use of these disks in controlling the STNO coupling
- This could be used for in-materio control using magnonic circuits rewritable with an MFM tip

3. Results

- A disk in the vortex state blocks the ability of synchronisation and the uniform state allows for the interaction

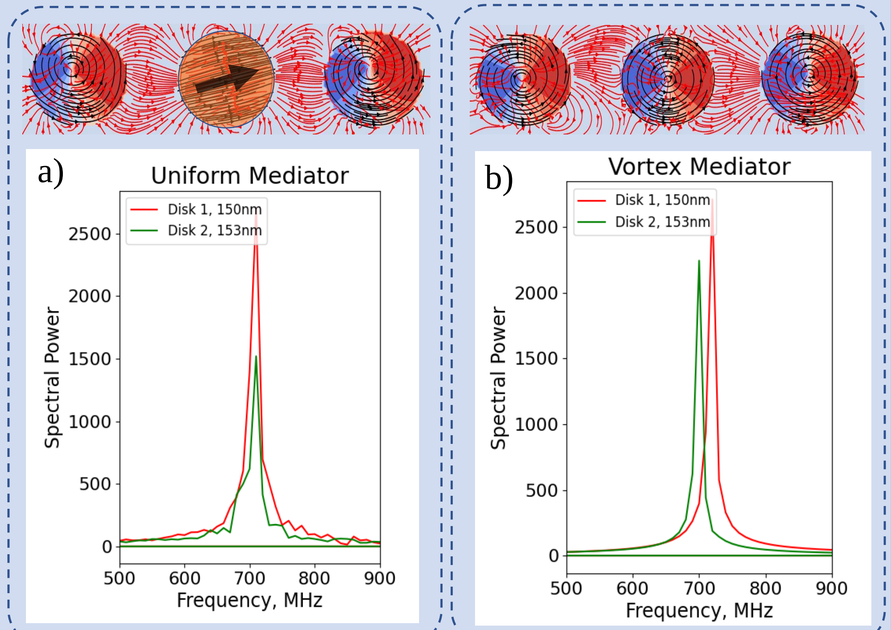


Figure 3. Synchronisation of 2 STNOs in states shown above a) synchronised state with a uniform mediator. b) unsynchronised state with a vortex mediator

- This can be leveraged in longer chains as seen in Figure 5
- Higher dimensional structures, such as square and triangular lattices of STNOs, are also promising but the coupling did not act as expected due to rotational freedom of the mediator

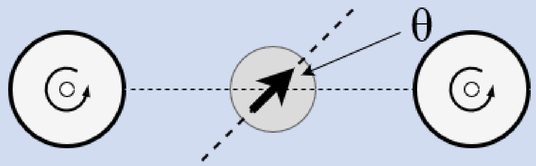


Figure 4 demonstrates rotational freedom of uniformly magnetised mediator.

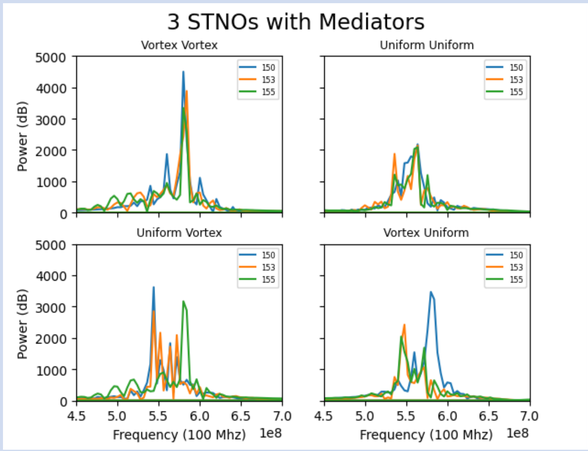


Figure 5 Synchronisation states of 3 STNOs in a line (150nm, 153nm, 155nm). Titles correspond the states of the mediators in order.

- This hypothesis was confirmed by measuring the frequency as a function of the mediator angle as below

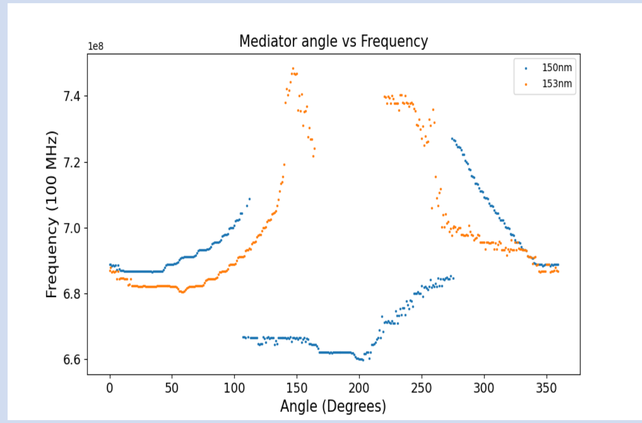


Figure 6 Shows the dependence of synchronisation on the angle of the mediator. Angle defined as in Figure 4

- STNOs synchronise most strongly when the mediator is directed between the disks and de-synchronise for large angles

4. Conclusion

- STNO coupling can be enhanced using uniform and blocked using vortex mediators
- The angular dependence of synchronisation leads to complex cross-structure interactions that need to be explored further for higher dimensional structures

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[1] Locatelli, Nicolas & Cros, Vincent & Grollier, Julie. (2013). Spin-torque building blocks. Nature materials. 13. 11-20. 10.1038/nmat3823.
[2] Lebrun, R., Tsunegi, S., Bortolotti, P. et al. Mutual synchronization of spin torque nano-oscillators through a long-range and tunable electrical coupling scheme. Nat Commun 8, (2017). https://doi.org/10.1038/ncomms15825
[3] Vansteenkiste, Arne & Leliaert, Jonathan & Dvornik, Mykola & Garcia-Sanchez, Felipe & Waeyenberge, Bartel. (2014). The design and verification of MuMax3. AIP Advances. 4. 10.1063/1.4899186.
[4] Stenning, Kilian et. al. (2020) Magnonic bending, phase shifting and interferometry in a 2D reconfiguarable nanodisk crystal. ACS Nano. 10.1021/acsnano.0c06894