Heusler-alloy nanocontact vortex oscillators

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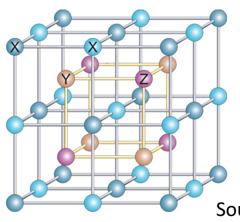
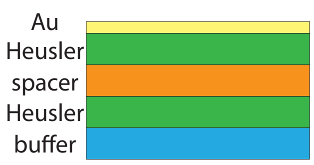
What is a Heusler alloy?



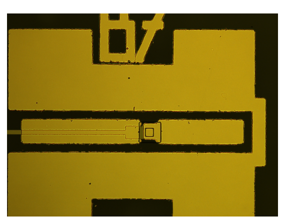
Magnetic FCC alloy with XYZ or X_2YZ composition (half and full Heusler). Can have very low Gilbert damping [1,2] and high spin polarization.

Source: Wikipedia

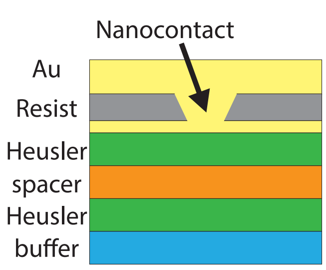
Fabrication process



MBE deposition of layers in Institut Jean Lamour to create a spin valve. Heusler are used for large GMR.

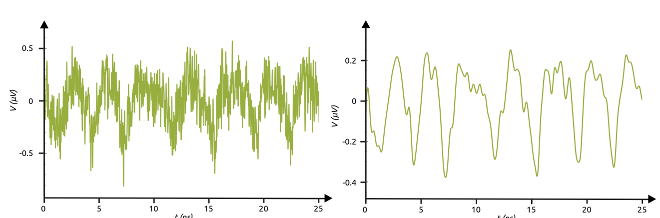


Optimized rf design (block surrounding signals with coaxial design) using optical lithography and etching to create electrodes.



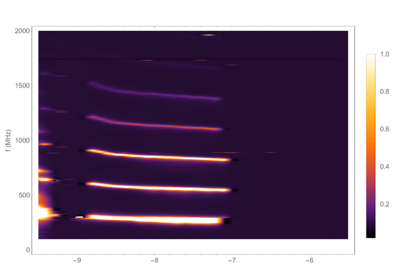
View from top of the sample above. Nanocontact (not visible) is in the central square. An AFM tip is used to indent a resist to create a nanocontact [6].
Stack (thickness in nm): MgO // Cr (20) / Co (5) / Co_2MnGe (5) / Au (2) / Co_2MnGe (15) / Au (2)

Low-pass filtering



Two time traces showing raw data (left) and filtered data (right) with a lowpass filter a cutoff at 1.6 GHz.

Signal extinction



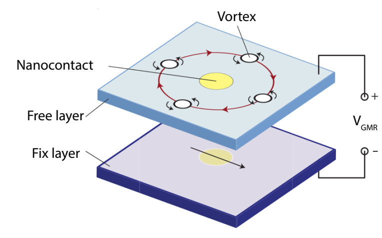
PSD map with DC current sweep. It shows a signal extinction between 9.3 and 9 mA. Because signal appears for higher and lower currents, it might rather indicates some in-phase synchronization mode between two vortices, in both free and fixed layer.

References

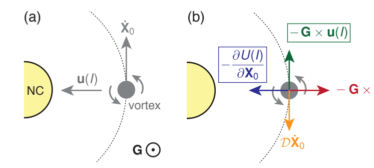
[1] T. Graf et al., *IEEE Trans. Magn.* 47 (2011), 367-373
[2] C. Guillemard et al., *PRApp.* 11 (2019), 062009
[3] S. Petit-Watelot et al., *Nat. Phys.* 8 (2012), 682-687
[4] T. Devolder et al., arxiv:1903.00921 [accepted in *PRL*]
[5] J. Létang et al., arxiv:1906.08492 [to appear in *PRB*]
[6] K. Bouzehouane et al., *Nano. Lett.* 3 (2003), 1599-1602

What is a magnetic vortex ?

A magnetic vortex is a whirling structure gyrating around a nanocontact in such an oscillator under a DC current. This gyration is described by equation and forces given in figure on right. Vortex topological number is ½, and is topologically stable in nanopillar systems. In nano-contact systems [3,4,5], high enough DC current is necessary to maintain the vortex



Representation of a vortex and its trajectory in a nanocontact spin-valve structure. Fix and free layers enable a GMR read-out of vortex dynamics



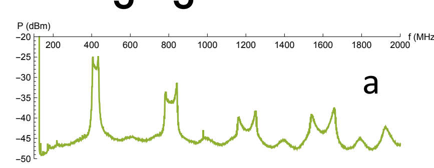
Forces on a vortex leading to its gyration around nanocontact. A Thiele equation describes this motion:

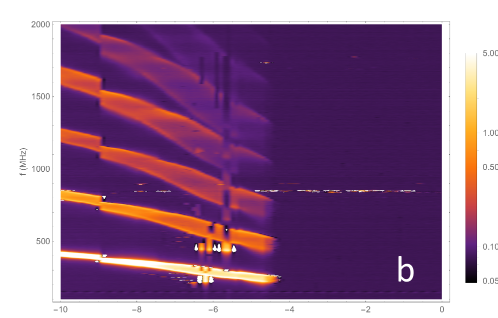
$$\mathbf{G} \times \left(\dot{\mathbf{X}}_0 - \mathbf{u}(\mathbf{X}_0, I)\right) + \mathcal{D} \cdot \dot{\mathbf{X}}_0 = -\frac{\partial U(I)}{\partial \mathbf{X}_0}$$

Experimental set up

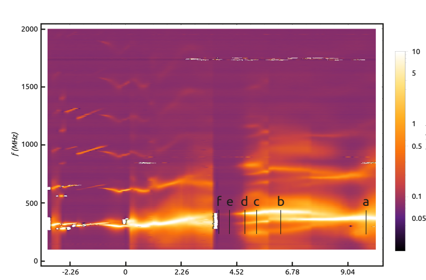
Device is placed in a six-coil set up. A DC current is injected to excite vortex gyration. Vortex gyration induces a GMR variation, resulting in a time varying voltage signal. This signal is analyzed in the frequency domain (spectrum analyzer) between 0.1 and 2 GHz and in the time domain (single-shot oscilloscope) at a rate of 80 GSa/s. Experiments are performed at room temperature.

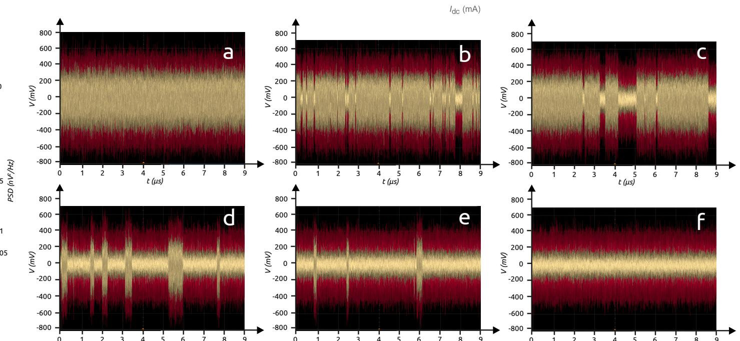
Imaging the vortex signal





Above and right: a) Example of PSD. Here two peaks and their harmonics are visible. b) All spectra such as the one in (a) are aggregated into one color-map to illustrate evolution with DC current. No signal below -4 mA indicates that the vortex stops gyrating below this threshold.

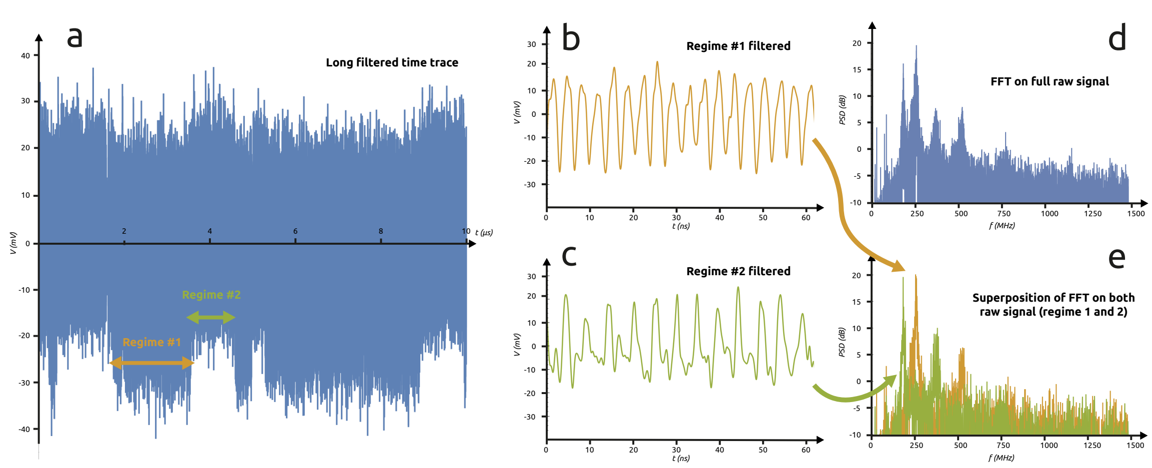




Above: PSD map with in-plane field variation. a) to f) subfigures give time traces at some specific field. Bordeaux ■ signal is raw data and beige ■ is filtered.

Below: a) 10 µs portion of a 10 ms time trace. b) and c) are zooms on two different oscillation regimes with 1.6 GHz lowpass filter. d) and e) are spectra from FFT of raw data (d) or selected time trace (d)

Mode hopping between two regimes as a function of in-plane fields. Filtered data show amplitude variation between modes. Long time traces were acquired in a bistable. Fast Fourier Transforms (FFT) reveal different frequencies associated with the modes (Fig. below).



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