Interactions between a pinned ferromagnetic vortex and individual nitrogen-vacancy spins

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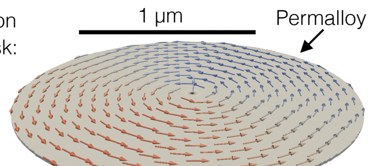
Introduction

Ferromagnetic vortex domains produce strong, localized, rapidly-tunable magnetic fields which may be useful for nanoscale spintronic or quantum information processing devices. Here, we map out how pinning affects the motion of a vortex, and subsequently the interaction of the vortex with individual nitrogen-vacancy spins.

Ferromagnetic vortex domains

Ground state magnetization of a soft ferromagnetic disk:

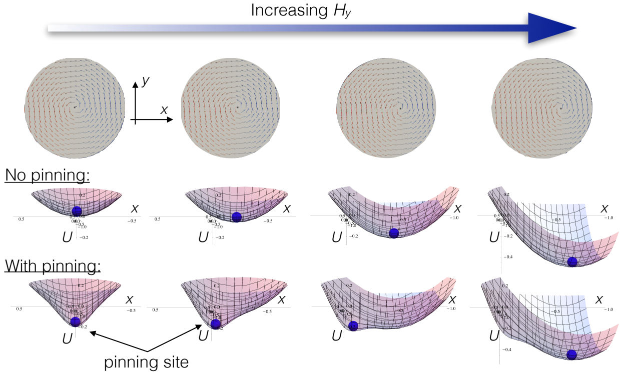
- in-plane magnetization circulating about core
- out-of-plane magnetization at vortex core (~10 nm diam.)



Micromagnetic simulation (OOMMF)

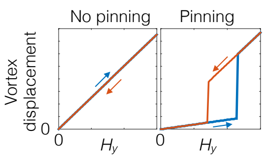
Vortex core position controllable via in-plane magnetic field:

Rigid vortex model — vortex core moves in effective potential: $U \approx \frac{1}{2}k\mathbf{r}^2 - k\chi_0 (H_y x + H_x y)$



Pinning results in:

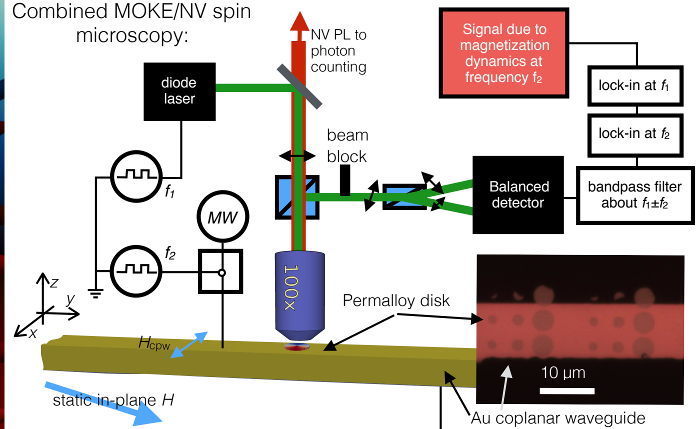
- Jumps in vortex position vs. H
- Hysteresis/bistability



[1] Badea, R, J. A. Frey, and J. Berezovsky. "Magneto-optical imaging of vortex domain deformation in pinning sites." J. Mag. Mag. Mat. 381 (2015): 463-469.

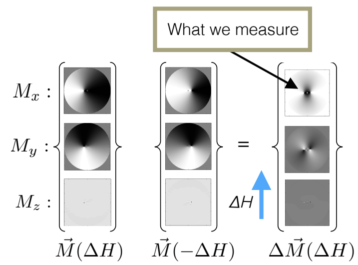
Mapping the vortex pinning potential

Combined MOKE/NV spin microscopy:

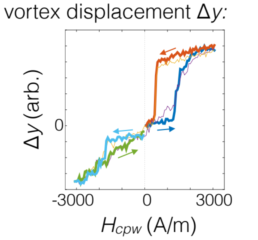


1. Differential MOKE microscopy measures difference in **M** between two values of H_{cpw}. [1]

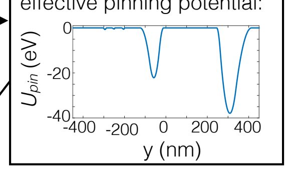
ΔM_x centered at the vortex core provides a measure of vortex core displacement Δy.



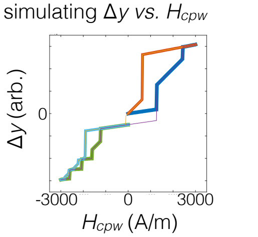
2. Sweeping H_{cpw} reveals vortex displacement Δy:



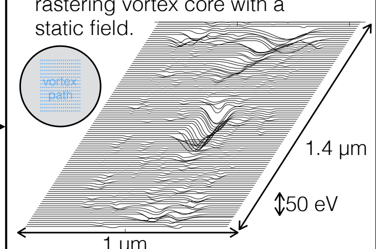
3. Positions of jumps yield effective pinning potential:



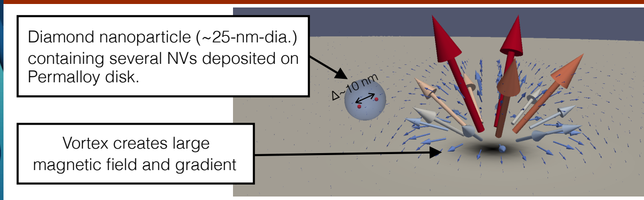
4. Verify pinning potential by simulating Δy vs. H_{cpw}



5. Map pinning potential by rastering vortex core with a static field.

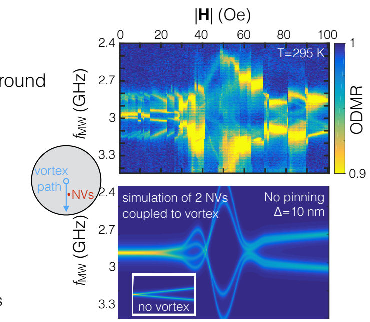


Coupling the pinned vortex to NV spins

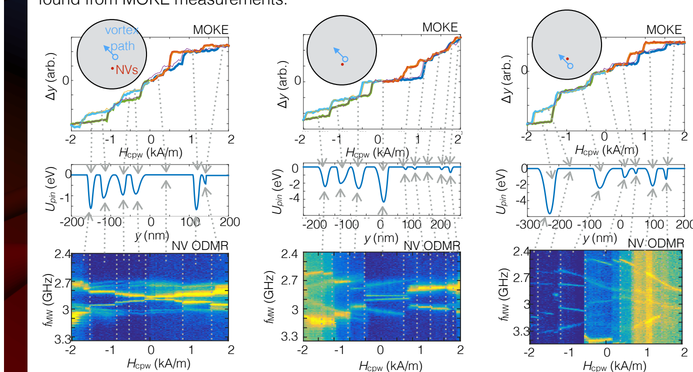


- Sweep vortex position using magnetic field.
- Measure spin splitting of NV ground states with optically-detected magnetic resonance (ODMR).

NV spin splitting shows sudden jumps vs. applied field



Jumps in NV spin splitting identified with transitions between pinning sites found from MOKE measurements:



Conclusions

- Differential MOKE microscopy yields vortex displacement vs. applied field, from which an effective pinning potential can be extracted.
- NV spins in a nanoparticle are split by several 100 MHz as the vortex approaches.
- The NV spin splitting changes mainly by discrete jumps associated with transitions of the vortex from one pinning site to another.

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