Effect of rounded corners on the magnetic properties of pyramidal-shaped shell structures

Andreas Knittel[1], Matteo Franchin[1], Farzad Nasirpouri[2], Simon J. Bending[3] and Hans Fangohr[1]

[1] Engineering and the Environment, University of Southampton
[2] Materials Engineering Faculty, Sahand University of Technology
[3] Department of Physics, University of Bath

UNIVERSITY OF Southampton
School of Engineering Sciences

Introduction

- We study chemically-grown **shell structures with pyramidal shape** (Fig. 1). A former work on such structures [1] has revealed the existence of an asymmetric vortex state (Fig. 2), which may have potential applications in the field of data storage (quadbit).
- Corners and edges of such structures always exhibit a certain degree of **rounding**.
- The rounding has an important effect on the stability of micromagnetic states [2] and thus on the magnetic properties of the samples.
- In this work, we investigate the **effects of edge and corner rounding** on
  - the **stability of the asymmetric vortex state**, and
  - the **reversal** of quasi-homogeneous micromagnetic states.

Method

- We use **micromagnetic simulations** and finite element discretization (Nmag software package [4]) to study pyramidal shell structures.
- We use a **realistic geometry** to model the pyramidal shells: the corners and edges are rounded. This increases the complexity of the geometry design (Fig. 3).
- We use **material parameters of nickel**: saturation magnetization M_{sat} = 493380 A/m, exchange coupling constant A = 7.2×10^{-12} J/m. The small magnetocrystalline anisotropy is neglected, $K_1 = 0$.
- We computationally study the **reversal process** (hysteresis loop) along the *x*-direction (see Fig. 1). For each value of the field, the magnetization is relaxed by integrating the Landau-Lifshitz equation with high damping, α = 1.0, to accelerate convergence.

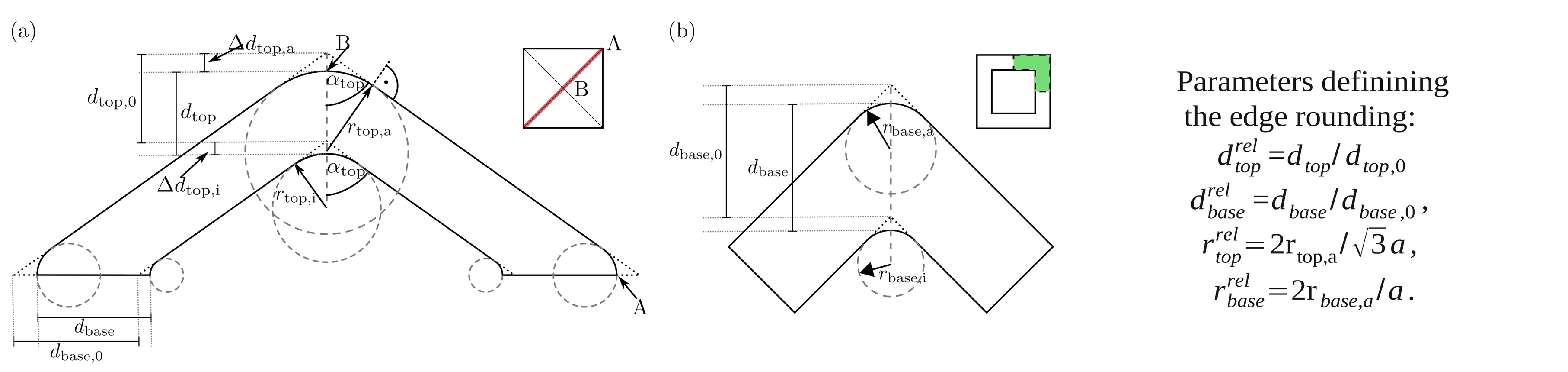

Figure 3: The rounding of the edges is defined in terms of four parameters. Small insets at the top right of each cross-section show the position of the depicted cross-sections with respect to the pyramidal shell.

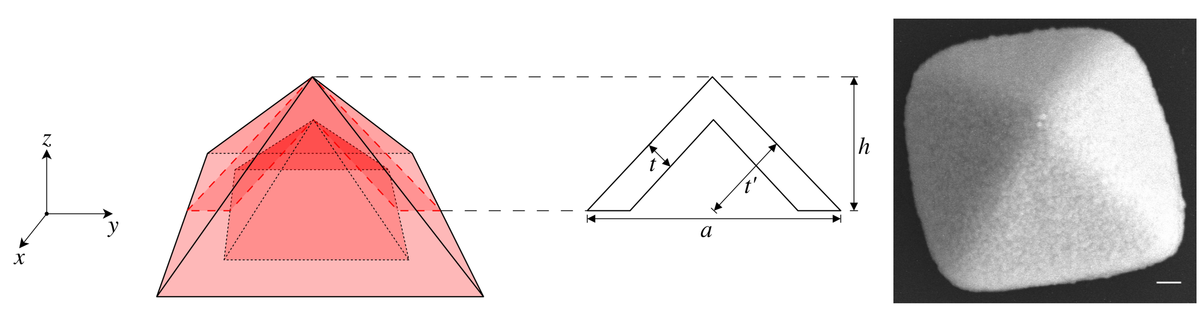

Figure 1: *Left:* geometric model of a pyramidal shell with sharp edges and corners. This geometry is described in terms of two parameters, a and t_{rel} = 100.0 % t/t`. Note, that the aspect ratio of the structure is kept constant, i.e. the height h is equal to a/2. The properties of such structures have been investigated before [2].
Right: atomic force microscope (AFM) image of a pyramidal-shaped core-shell structure with a silver core and a nickel shell. The rounding of the edges of the nickel shell is clearly visible. The reference bar corresponds to 1 μm.

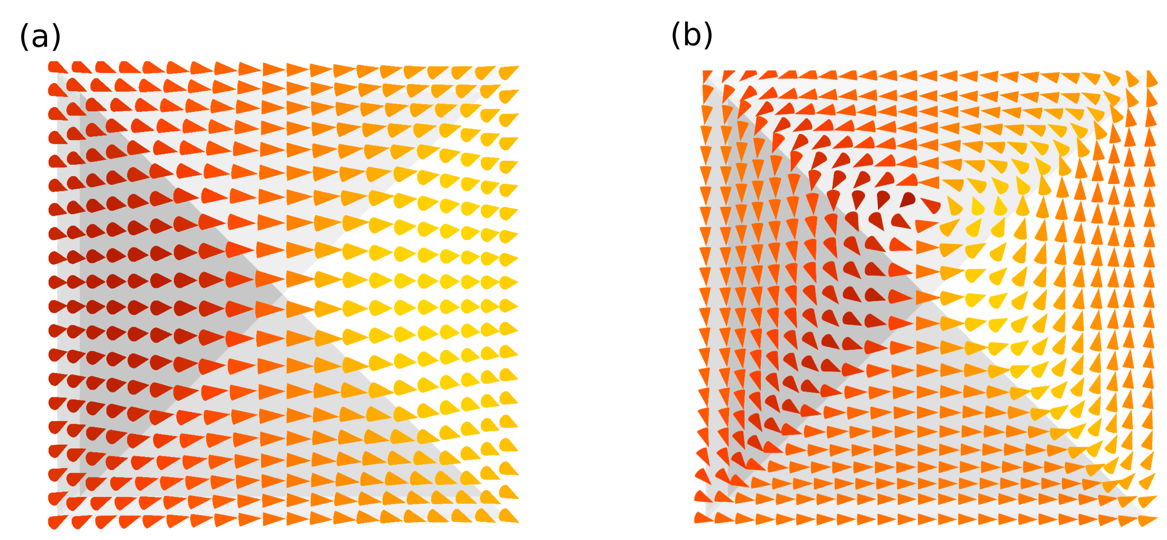

Figure 2: Micromagnetic states in pyramidal shells with sharp edges from a top-down perspective. (a) Flower state (geometry parameters: a = 120 nm, t_{rel} = 10 %): The magnetisation is nearly homegeneous. (b) Asymmetric vortex state (a = 300nm, t_{rel} = 10%): More magnetic moments point to the right than to the left. Therefore, a small external field to the left can switch the vortex core to the bottom triangular side face.

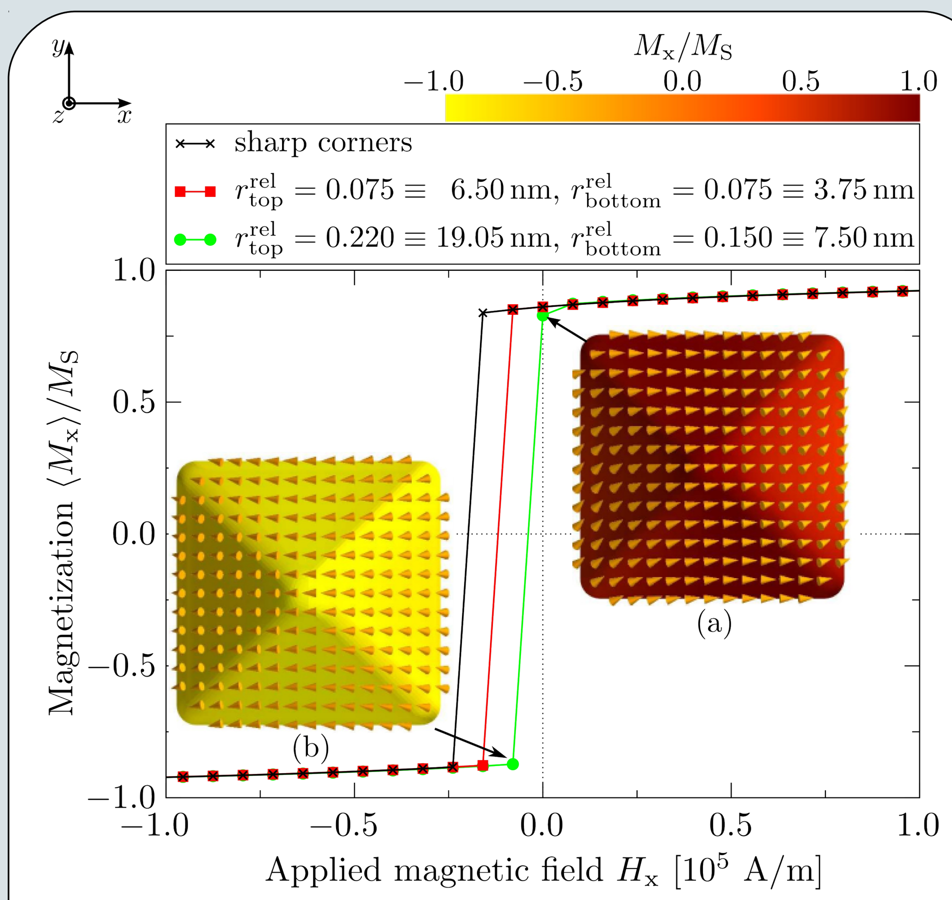

Figure 4: The magnetic reversal along the x-direction is shown for pyramidal shells with *a* = 100 nm and t_{rel}=10 % and different degrees of rounding at the corners and edges. The black curve corresponds to the reversal of a pyramidal shell with sharp corners and edges. The geometries, which correspond to the green and red curve respectively, have been created with $d^{rel}_{base} = d^{rel}_{top} = 1.0$, and the parameters given in the legend. The two insets give on-top views of the micromagnetic configurations corresponding to the indicated data points of the green curve (color bar and coordinate axes are shown at the top).

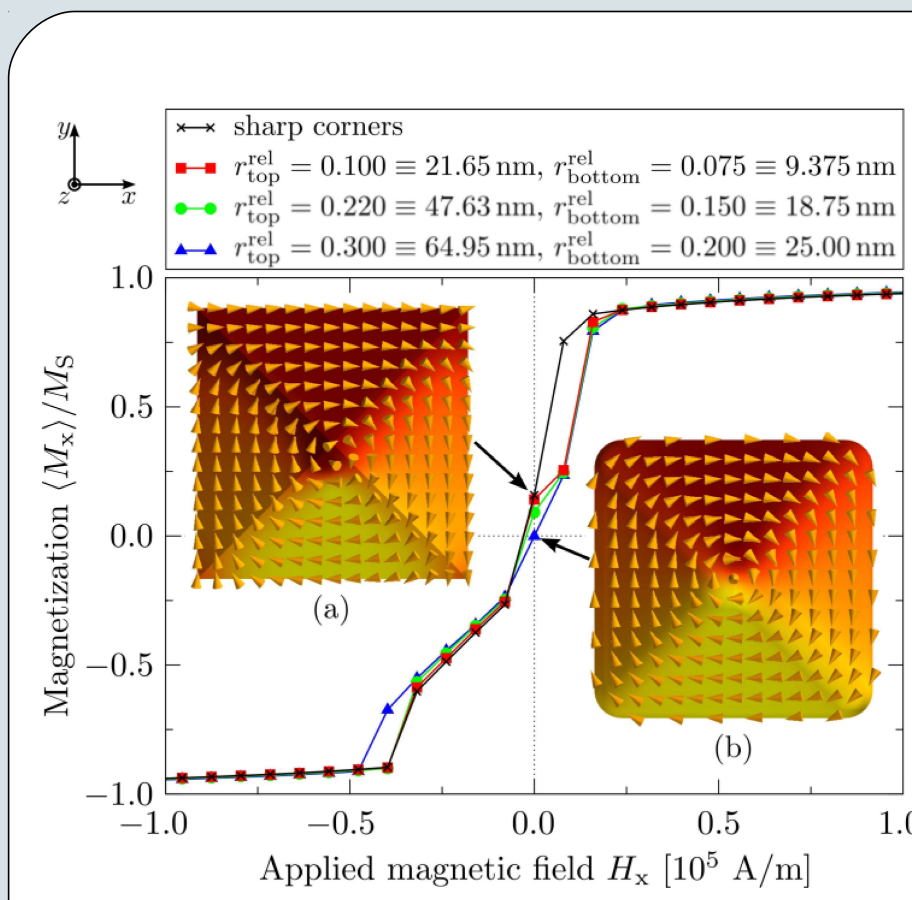

Figure 5: The magnetic reversal along the x-direction is shown for pyramidal shells with *a* = 250nm and t_{rel}=50% and different degrees of rounding at the corners and edges. The black curve corresponds to the reversal of a pyramidal shell with sharp corners and edges. The geometries for the green, red and blue curve have all been created using $d^{rel}_{base} = d^{rel}_{top} = 1.0$, and the parameters given in the legend. The two insets show on-top views of the micromagnetic configurations corresponding to the indicated data points of the black and blue curve, respectively. The color scheme is shown in Fig. 5.

Results

- **The rounding of edges and corners has a significant effect on the coercivity** (Fig. 4), even for small degree of rounding (curvature below the nickel exchange length, L_{exch}=6.86 nm). Indeed, even a small rounding can supress the diverging demagnetisation fields which are typically originated by sharp corners and edges.
- The green data curve exhibits a so called **S-state at remanence**, which differs from the flower state observed for the corresponding structure with sharp corners and edges (see Fig. 2). Therefore, **edge rounding can qualitatively change the micromagnetic states**.
- Fig. 5 shows the effect of rounding on a magnetic reversal curve, which, in the case of no rounding, exhibits a asymmetric vortex state at remanence. It is demonstrated that a substantial degree of rounding has to be introduced (curvature radii of above 4 L_{exch}, blue curve) in order to suppress the asymmetric vortex state at remanence. This can be readily seen as only the blue data curve crosses the origin of the coordinate system.

Conclusions

- Rounded corners and edges can have a **significant effect on the coercitivity and on the micromagnetic states** involved in the reversal process;
- The **asymmetric vortex state** observed in the sharp pyramidal geometry [1] **is well preserved** when rounding is introduced. This finding is important with regard to potential technological applications, as edges and corners do always present a certain degree of rounding in realistic structures.

References

[1] A. Knittel et al., New Journal of Physics, **12**, 113048 (2010)
[2] L. Thevenard et al. Journal of Applied Physics, **106**, 063902, (2009)
[3] F. Nasirpouri et al., Applied Physics Letters **98**, 222506 (2011)
[4] nmag.soton.ac.uk

Acknowledgements

This work was supported by EPSRC in the UK under grants EP/E039944/1 and EP/E040063/1, DYNAMAG project (EU FP7/2007-2013 Grant No. 233552).