Publication List

Jutta Steiner

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1 Articles in peer-reviewed journals

[Ste+11] J. Steiner, H. Wieczoreck, R. Schäfer, J. McCord, and F. Otto. "The formation and coarsening of the concertina pattern." 2011, accepted by Phys. Rev. B. URL: http://arxiv.org/abs/1106.3573v1.

[AFS10] F. Alouges, S. Faure, and J. Steiner. "The vortex core structure inside spherical ferromagnetic particles." In: *Discrete And Continuous Dynamical Systems A* 27.4 (2010), pp. 1259–1282. URL: http://aimsciences.org/journals/displayArticles.jsp?paperID=5026.

[LoB+10] M. LoBue, F. Mazaleyrat, M. Ammar, R. Barrué, Y. Champion, S. Faure, M. Hÿtch, E. Snoeck, J. Steiner, and F. Alouges. "Observation and modelling of magnetic vortex core structure in Permalloy nanoparticles." In: *Journal of Magnetism and Magnetic Materials* 322.9-12 (May 2010), pp. 1290–1292. URL: http://adsabs.harvard.edu/abs/2010JMMM..322.1290L.

[OS10] F. Otto and J. Steiner. "The concertina pattern: From micromagnetics to domain theory." In: *Calculus of Variations and Partial Differential Equations* 39 (1 2010), pp. 139–181. URL: http://www.springerlink.com/content/p262014214q24050/fulltext.pdf.

[CÁOS07] R. Cantero-Álvarez, F. Otto, and J. Steiner. "The concertina pattern: a bifurcation in ferromagnetic thin films." In: *J. Nonlinear Sci.* 17.3 (2007), pp. 221–281. URL: http://www.springerlink.com/content/92m2lh7842710350/fulltext.pdf.

2 Preprints

[Ste08] J. Steiner. "Compactness for the asymmetric Bloch wall." In: *SFB Preprint* 372 (2008). URL: http://sfb611.iam.uni-bonn.de/uploads/374-komplett.pdf.

3 Theses

[Ste10] J. Steiner. "The formation of the concertina pattern: Experiments, analysis, and numerical simulations." 2010, Doctoral thesis. URL: http://hss.ulb.uni-bonn.de/2011/2618/2618.pdf.

[Ste06] J. Steiner. "Reduzierte Modelle für dünne ferromagnetische Filme: Analysis und Numerik." 2006, Diploma thesis, University of Bonn.

4 Abstracts

4.1 Articles in peer-reviewed journals

[Ste+11]

The concertina is a magnetization pattern in elongated thin-film elements of a soft ferromagnetic material. It is a ubiquitous domain pattern that occurs in the process of magnetization reversal in direction of the long axis of the small element.

Van den Berg argued that this pattern grows out of the flux closure domains at the sample's tips as the external field is reduced. Based on experimental observations and theory, we argue that in sufficiently elongated thin-film elements the concertina pattern rather bifurcates from an oscillatory buckling mode. Typical sample widths and thicknesses are of the order of a couple of ten micro-meters and of the order of a couple of ten nano-meters, respectively.

Using a reduced model that is derived by asymptotic analysis from the micromagnetic energy and that is also investigated by means of numerical simulation, we quantitatively predict the average period of the concertina pattern and qualitatively predict its hysteresis. In particular, we argue that the experimentally observed coarsening of the concertina pattern is due to secondary bifurcations related to an Eckhaus instability.

We also link the concertina pattern to the magnetization ripple and discuss the effect of a weak (crystalline or induced) anisotropy.

[AFS10]

We analyze the vortex core structure inside spherical ferromagnetic particles through both a bifurcation analysis and numerical simulations. Based on properties of the solution and simplifying assumptions, specific numerical algorithms are developed. Numerical results are provided showing the applicability of the methods.

[LoB+10]

We use an approximate micromagnetic model, based on geometrical simplifications of the problem, to describe the vortex core structure observed in spherical Permalloy nanoparticles using off-axis electron holography. The magnetisation distribution inside the vortex core is directly calculated by minimising the micromagnetic energy functional and is compared with the experimental results. The symmetry constraints underlying the model are discussed envisaging possible generalisation to the case of vortex cores with structure strongly dependent on the coordinate directed along the axis of the vortex. Moreover the many-body effect associated with the presence of two small satellite particles is described by rescaling the size of the particle.

[OS10]

This is a continuation of a series of papers on the concertina pattern. The concertina pattern is a ubiquitous metastable, nearly periodic magnetization pattern in elongated thin film elements. In previous papers, a reduced variational model for this pattern was rigorously derived from 3-d micromagnetics. Numerical simulations of the reduced model reproduce the concertina pattern and show that its optimal period w_{opt} is an increasing function of the applied external field h_{ext}. The latter is an explanation of the experimentally observed coarsening. Domain theory, which can be heuristically derived from the reduced model, predicts and quantifies this dependence of w_{opt} and h_{ext}. In this paper, we rigorously extract these heuristic observations of domain theory directly from the reduced model. The main ingredient of the analysis is a new type of estimate on solutions of a perturbed Burgers equation.

[CÁOS07]

The concertina pattern is a metastable stage in the switching process of elongated thin-film elements. It is an approximately periodic structure of domains, separated by walls perpendicular to the long axis of the element. In this paper, we give arguments in favor of our claim that the period is frozen-in at nucleation, i.e., at the critical external field. In prior work, R. Cantero-Alvarez and F. Otto, Journal of Nonlinear Science (2006), we argued that there are four qualitatively different regimes for nucleation. In one of these asymptotic regimes, the unstable mode displays an oscillatory behavior in the direction of the long axis. In this work, we derive a scaling limit of the micromagnetic energy near the bifurcation point in the above regime. We also prove that the scaling limit is coercive for all values of the reduced external field. Because of this coercivity, there exists a branch of nontrivial local minimizers. Numerical minimization of the scaling limit reveals that this branch is indeed a continuous branch of concertina pattern. The scaling limit is derived by Γ-convergence of the suitably rescaled micromagnetic energy. This robust procedure combines the limit of an asymptotic parameter regime with a zoom-in in configuration space. The coercivity of the scaling limit is derived by suitable nonlinear interpolation estimates.

4.2 Preprints

[Ste08]

We study a variational model for the magnetization in a ferromagnetic sample that is given by

$$e(m) := \delta^2 \int_{\omega' \times (-\frac{\tau}{2}, \frac{\tau}{2})} |\nabla m|^2 \, \mathrm{d}\, x + \int_{\mathbb{R}^3} ||\nabla|^{-1} \nabla \cdot m|^2 \, \mathrm{d}\, x,$$

where $m : \omega' \times (-\frac{\tau}{2}, \frac{\tau}{2}) \subset \mathbb{R}^3 \to \mathbb{S}^2$. The behavior of magnetizations m in the regime $\delta \ll \tau \ll 1$ is investigated. In the limit, optimal magnetizations are expected to be of the form $m' : \omega' \to \mathbb{S}^1$ with $\nabla' \cdot m' = 0$. Typically, solutions m' to this equation with $|m'|^2 = 1$ are not smooth, instead they exhibit line singularities. For finite τ these discontinuities are approximated by smooth transitions, so called asymmetric Bloch walls whose line energy density scales as δ^2. We prove strong compactness for a sequence of magnetizations with energy $e(m) \lesssim \mathrm{diam}(\omega')\, \delta^2$ in the regime $\delta^2 \leq \tau^3$. This justifies the heuristics on the limit magnetizations above. Unfortunately, the regime $\delta^2 \lesssim \tau^3$ is smaller than the regime in which the asymmetric Bloch wall is the energetically optimal transition layer.

4.3 Doctoral thesis

[Ste10]

The concertina is a magnetization pattern observed in elongated thin-film elements of a soft-magnetic material during the switching-process by an external magnetic field. The almost periodic pattern consists of stripe-like quadrangular and triangular domains of uniform, in-plane magnetization. The domains are separated by so-called walls in which the magnetization quickly turns. The main goal of this thesis consists in the analytical and numerical investigation of the formation and coarsening – which is closely related to the hysteresis of the switching-process – of the pattern starting from the micromagnetic energy functional. Experimental observations of very elongated samples suggest that the concertina pattern bifurcates from an oscillatory buckling mode simultaneously all over the sample. The existence of a corresponding parameter regime was confirmed on the level of a linear stability analysis based on the micromagnetic energy. On the basis of a reduced model derived in that particular parameter regime, we analytically (interpolation estimates, stability and Bloch-wave analysis, etc.) and numerically (numerical bifurcation, path-following, branch-switching, etc.) investigate the formation and the coarsening of the pattern. We quantitatively predict the average period of the concertina pattern and qualitatively predict the coarsening and the hysteresis. We show that on a mesoscopic scale the pattern corresponds to a weak solution of Burgers' equation where walls can be interpreted as shocks. On the theoretical side, the main ingredients are given by non-linear interpolation estimates derived from the analysis of the inhomogeneous Burgers equation and a Bloch wave analysis linking the concavity of the minimal energy per period to a modulation instability (Eckhaus instability) of the pattern that is at the origin of the coarsening. With the help of a numerical bifurcation analysis, we are able to systematically compute all metastable states. Finally, we also link the concertina pattern to the magnetization ripple and discuss the effect of a weak (crystalline or induced) anisotropy.