Downloaded from orbit.dtu.dk on: Apr 17, 2024

DTU Library

Micromagnetic simulations with realistically-generated sintered microstructures

Insinga, A.R.; Poulsen, E.B.; Bjørk, R.

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

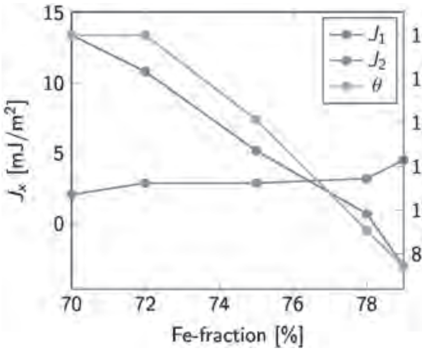
Link back to DTU Orbit

Citation (APA):
Insinga, A. R., Poulsen, E. B., & Bjørk, R. (2022). *Micromagnetic simulations with realistically-generated sintered microstructures*. 465-466. Abstract from 15th Joint MMM-Intermag Conference, New Orleans, United States.

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



Simulation results for different RuFe-spacer-layer compositions.

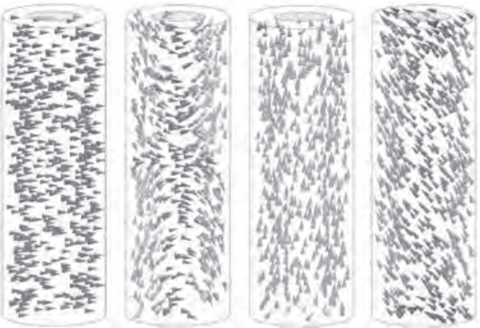
HOM-03. Withdrawn

HOM-04. Wave reversal mode: A new magnetization reversal mechanism in magnetic nanotubes.

J. Escrig[1,2], N. Bajales[3,4], D.M. Arciniegas Jaimes[3], S. Raviolo[3,4] and J.M. Carballo[5] *1. Department of Physics, Universidad de Santiago de Chile, Santiago, Chile; 2. Center for the Development of Nanoscience and Nanotechnology, Santiago, Chile; 3. CONICET, Córdoba, Argentina; 4. Universidad Nacional de Córdoba, Córdoba, Argentina; 5. Universidad Nacional de Río Cuarto, Río Cuarto, Argentina*

The wave reversal mode is a magnetization reversal mechanism that appears in ferromagnetic nanotubes of certain geometric parameters when an external magnetic field is applied perpendicular to their axes. The distinctive feature of this mode is that leads to well-defined S-shaped hysteresis curves [1]. In order to gain insight into the stability of this latter effect, we have performed micromagnetic simulations for permalloy and nickel nanotubes obtaining a non-monotonic behavior for coercivity as well as for remanence as a function of nanotube diameter for both materials. Motivated on these latter intriguing results, we found that measuring the area that encloses the hysteresis curve is a novel and simple strategy to identify the appearance of the wave reversal mode [2]. An additional contribution of this work is the proposal of a new magnetic phase diagram that allows determining the stability of this reversal mechanism as a function of the geometric and magnetic parameters of the tubes [2]. The authors acknowledge the access to Mendieta cluster (CCAD-UNC) and financial support from SECYT-UNC, MINCyT 2019, Fondecyt 1200302, Basal Project AFB180001 and Programa Escala Docente AUGM.

[1] S. Raviolo, D. M. Arciniegas Jaimes, N. Bajales, J. Escrig, J. Magn. Magn. Mater. 497, 165944 (2020). [2] D. M. Arciniegas Jaimes, S. Raviolo, J. M. Carballo, N. Bajales, J. Escrig, J. Magn. Magn. Mater. 523, 167578 (2021).



HOM-05. Micromagnetic simulations with realistically-generated sintered microstructures.

A.R. Insinga[1], E.B. Poulsen[1] and R. Bjørk[1] *1. Energy Conversion and Storage, Technical University of Denmark, Copenhagen, Denmark*

Micromagnetic simulations are used to predict the behavior of permanent magnet materials and compute magnetic hysteresis loops. Using this approach, we investigate the phenomenon of demagnetization and calculate the coercive force for realistically generated microstructures. Instead of employing the well-established but highly idealized approach based on Voronoi diagrams to generate microstructures [1], we generate polycrystalline microstructures using a kinetic Monte Carlo numerical model that simulates the constrained sintering process by including the effect of local stresses arising during the sintering [2]. An example of a microstructure with different colored grains generated using this approach is shown in Fig. 1(a). The micromagnetic simulation is then performed using the micromagnetism and magnetostatic framework MagTense [3, 4]. This framework has the unique capability of handling variable-size meshes by considering the exact analytical expression of the demagnetization field corresponding to the various mesh elements. By taking advantage of this capability, we employ a mesh-refinement procedure [5] that creates meshes that are more refined in the inter-grain soft phase, i.e. where the onset of the demagnetization phenomenon is most likely to occur. An example of variable-size mesh is shown in Fig. 1(b). As shown in the figure, the mesh in this example is composed by blocks of three different sizes. An example of hysteresis loop computed using our approach is shown in Fig. 2. We consider the effect of the statistical misalignment between the easy-axis directions of the different crystal grains. Moreover, we compare out realistic microstructures generation framework with the traditional Voronoi-structures and furthermore investigate the effect of the thickness of the inter-grain region, the effect of inclusions and porosity of the material, and the effect of different grain-size distributions. Our investigation highlights which qualities and features of the microstructure have the most significant impact on the ability of the magnet to resist an opposing field. Therefore, it is an important step towards optimizing the fabrication process and developing new and improved magnetic materials.

[1] J. Fischbacher, A. Kovacs, M. Gusenbauer, H. Oezelt, L. Exl, S. Bance and T. Schrefl, J. Phys. D: Appl. Phys. 51, (19), 193002 1-17, (2018). [2] R. Bjørk, H.L. Frandsen and N. Pryds, Proceedings of the International Conference on SINTERING 2014, (2014). [3] K.K. Nielsen and R. Bjørk, MagTense, https://doi.org/10.11581/DTU:00000071 (2019). [4] R. Bjørk, E.B. Poulsen, K.K. Nielsen and A.R. Insinga, J. Magn. Magn. 535, 168057 1-8, (2021). [5] K.K. Nielsen, C.R.H. Bahl, A. Smith and R. Bjørk, J. Phys. D: Appl. Phys. 50, (41), 414002 1-9, (2017).

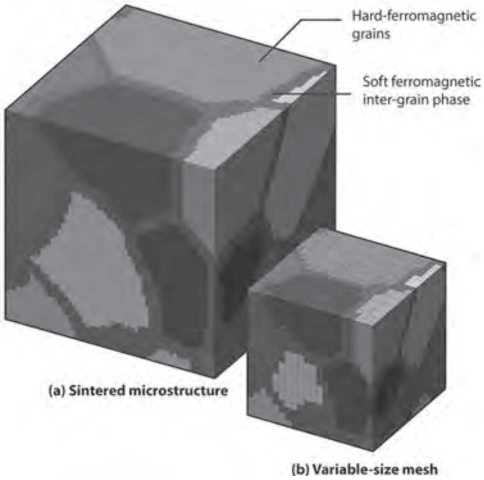


Fig. 1

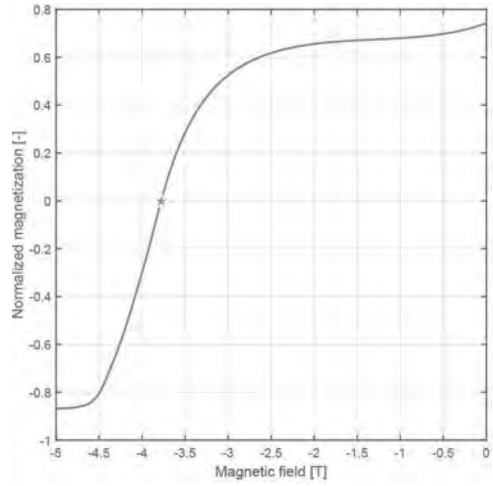


Fig. 2

HOM-06. Normal modes description of nonlinear magnetization dynamics in micromagnetic systems.

S. Perna[1], F. Bruckner[2], C. Serpico[1], D. Suess[2] and M. d'Aquino[1] *1. DIETI, University of Naples Federico II, Naples, Italy; 2. University of Vienna, Vienna, Austria*

The study of magnetization dynamics is fundamental in the analysis and design of high-speed nanoscale spintronic devices[1]. Recently, ultrafast magnetism also emerged as prolific research field promising magnetic devices working up to the THz range[2,3,4] with low power, scalability and compatibility with CMOS electronics[5]. Magnetization dynamics in such devices is usually studied by solving the Landau-Lifshitz-Gilbert (LLG) equation discretized on a grid of computational cells with edges smaller than the exchange length. This equation is then reduced to a nonlinear many-body evolution problem in which the state variables are magnetization vectors defined on the grid. In this work, a novel approach is adopted where magnetization is expanded in terms of magnetic normal modes which, contrary to classical plane waves, do take into account proper boundary conditions for confined structures[6]. The LLG equation is rewritten as a system of coupled nonlinear ODEs where the unknowns are the amplitudes of the normal modes[7]. Then, nonlinear magnetization dynamics starting from an equilibrium driven by time-varying magnetic fields or spin-torques can be quantitatively described by using a reduced number of normal modes. This is shown to occur in several magnetic systems relevant to applications such as magnetic nanodots and magnonic waveguides. The aforementioned normal modes model (NMM) permits describing spatially-nonuniform and nonlinear magnetization dynamics with a far reduced complexity compared to full micromagnetic simulations. Moreover, for a given magnetic structure, it allows to study far from equilibrium steady-state regimes as function of amplitude, spatial distribution and time-variation of the external excitation without having to repeat full-scale simulations for each set of excitation parameters. As an example, we analyze the ac spin-torque driven nonlinear ferromagnetic resonance (FMR) response of a cylindrical nanodot (50 nm radius, 12 nm thick). The appearance of fold-over effect at frequency 11 GHz higher than that of fundamental mode (3 GHz) is due to the 5th normal mode (see fig. 1).

[1] B. Dieny et al., Opportunities and challenges for spintronics in the microelectronics industry. Nature Electronics 3, 446-459 (2020). [2] Bigot, J.-Y. and Vomir, M. (2013), Ultrafast magnetization dynamics of nanostructures. ANNALEN DER PHYSIK, 525:2-30.https://doi.org/10.1002/andp.2012001992 [3] Zhang, W., Maldonado, P., et al. Ultrafast terahertz magnetometry. NatCommun 11, 4247 (2020). https://doi.org/10.1038/s41467-020-17935-6 [4] Neeraj, K., Awari, N., et al. Inertial spin dynamics in ferromagnets. Nat.Phys. 17, 245–250 (2021). https://doi.org/10.1038/s41567-020-01040-y [5] Makarov, A., Windbacher, T., et al. CMOS-compatible spintronic devices:a review. Semicond. Sci. Technol. 31 113006 (2016). [6] M. d'Aquino, C. Serpico, et al. A novel formulation for the numerical computation of magnetization modes in complex micromagnetic systems, J. Comp.Phys., 228 (2009), 6130-6149. https://doi.org/10.1016/j.jcp.2009.05.026[7] Perna, S., Bruckner, F., et al. Computational Micromagnetics based on Nor-mal Modes: bridging the gap between macrospin and full spatial discretization. arXiv:2105.08829

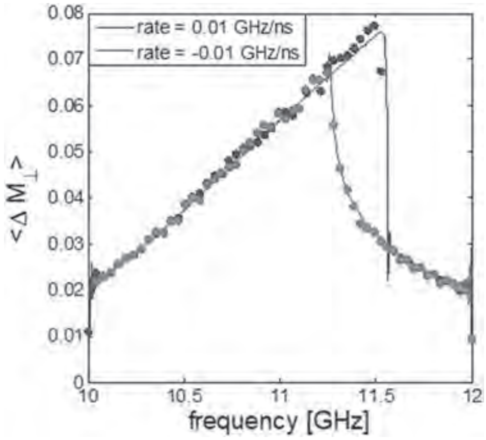


Figure 1: computed FMR response. Solid lines (filled dots) refer to NMM (full micromagnetic simulations).

HOM-07. Physics informed neural networks for computational magnetism.

T. Schrefl[1,2], A. Kovacs[1,2], J. Fischbacher[1,2], M. Gusenbauer[1,2], M. Hovorka[1,2] and H. Oezelt[2] *1. Christian Doppler Laboratory for Magnet Design through Physics Informed Machine Learning, Wiener Neustadt, Austria; 2. Department for Integrated Sensor Systems, Danube University Krems, Wiener Neustadt, Austria*

With the rise of deep learning, physics informed neural networks [1] became an alternative to finite element simulation in many fields of materials and device design. Physics informed neural networks bring several advantages as compared to traditional numerical methods for solving partial differential equations like finite differences or finite elements: 1. There is no need for mesh generation. 2. Inverse problems may be solved effectively. 3. A whole family of problems may be solved with a single neural network. We demonstrate how physics informed neural networks can be applied in magnetostatics and micromagnetics. The approach is like the Ritz method for computing the magnetic field or the magnetization. However, instead of finite element basis functions [2], we use dense neural networks to approximate the unknowns. The underlying physics is incorporated through the loss function which is minimized during training of the neural network. We first applied physics informed neural network to solve a classical inverse problem in magnetism. We searched for the magnetization in a hollow cylinder that produces a uniform field in the hole and has zero field outside. The mean relative error between the neural network estimate and the analytic solution for the magnetization was 0.27 percent. We computed the demagnetization curve of a $Nd_2Fe_{14}B$ particle. The difference between the finite element solution and the neural network estimate was 0.9 percent. We computed the lowest eigenvalue of Brown's linearized micromagnetic euqation to get the nucleation field for a soft magnetic defect in a hard magnetic matrix. The mean realtive error for the nucleation field of an Fe inclusion in $Sm_2Fe_{17}N_3$ as function of defect size was 0.4 percent as compared to the analytic solution [3]. Because of the ability to solve multiple problems simulateneously, physics informed neural networks have a great potential for optimization and tailoring the magnet's internal structure to achieve a specific demagnetiation curve. The financial support by the Austrian Federal Ministry for Digital and Economic Affairs, the National Foundation for Research, Technology and Development and the Christian Doppler Research Association is gratefully acknowledged.