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Editorial

Recent Advances in Nanomagnetism

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Nanomagnetism covers a broad range of research in magnetism and magnetic properties of low-dimensional systems, including both experimental methods in sample fabrication and characterization, as well as theoretical modeling and simulations. Size limitations in one, two, and three dimensions have led to a number of technologically important developments, having an extensive range of applications in sensors and activators, notably in the magnetic recording industry and spintronic devices and more recently in biomedical applications. Magnetic systems can have a variety of symmetries, from thin film geometries to wires and dots, as well as a number of nanoparticle structures, which can also have core-shell substructures. The magnetic state of nanometric magnetic structures results from the equilibrium between competing magnetic anisotropies, interactions, and the applied magnetic field. This can produce a number of phenomena, such as exchange bias effects, skyrmions, as well as magnetic instabilities, which can lead to superparamagnetic effects in magnetic nanoparticles and nanostructures. The physical dimensions and shape of a magnetic structure, as well as its intrinsic magnetic anisotropies, will determine whether it is a single domain or has a more complex magnetic domain structure. Traditionally patterned nanostructures have been arrays of nanomagnets, though recent trends have shown how this can be extended to three-dimensional structures where more complex magnetic configurations are possible and give rise to unprecedented magnetic properties.

This special issue on *Recent Advances in Nanomagnetism* includes six contributions covering a broad spectrum of interests in the topics from magnetic nanoparticles to perpendicular magnetic anisotropies, and from magnetization textures to magnetizations dynamics in magnetic nanostructures. This special issue should contain subjects of interest for researchers in nanomagnetism and current developments in magnetism.

The first contribution is by *P. Ziogas* and *A. B. Bourlinos* from the University of Ioannina (Greece), *J. Tucek* from the University of Pardubice (Czech Republic), *O. Malina* from Palacky University Olomouc and *A. P. Douvalis* from the University Research Center of Ioannina (Greece), ref. [1], presents a study of the synthesis and characterization of novel magnetic properties of iron-based magnetic nanoparticles, which are composed of spinel type iron oxides to iron carbide nanoparticles. These are prepared by thermal processing in vacuum at varying annealing temperatures, whereby fine maghemite (γ-Fe_2O_3) nanoparticle seeds are deposited on the surface of nanodiamond nanotemplates. The resulting nanoparticles vary from fine dispersed spinel-type non-stoichiometric 5 nm magnetite ($Fe_{3-x}O_4$) nanoparticles at low annealing temperatures, to 10 nm single-phase cementite (Fe_3C) iron-carbide structures for intermediate annealing temperatures. Larger Fe_3C and Fe_5C_2 iron-carbides are produces for higher annealing temperatures. The magnetic properties of the nanoparticles have been characterized using magnetometry and thermomagnetic measurements as well as Mössbauer spectroscopy, with properties ranging from superparamagnetic to soft and hard ferromagnetic behavior.

The contribution by *S. A. Pathak* and *R. Hertel* from the University of Strasbourg (France), ref. [2], concerns a theoretical study of various aspects of geometrically constrained skyrmions, which are magnetization textures formed by a swirling of the magnetization and typically have nanometric dimensions. The geometric contraint in this study is introduced via a thickness modulation of a thin film host material, FeGe. Dot-like pockets are introduced, forming preferential sites for the skyrmion formation and act as pinning

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Citation: Schmool, D.S. Recent Advances in Nanomagnetism. *Magnetochemistry* **2022**, *8*, 110. https://doi.org/10.3390/magnetochemistry8090110

Received: 13 September 2022
Accepted: 14 September 2022
Published: 19 September 2022

centers. Such skyrmionic structures could have important applications for data storage in racetrack-like shift register devices.

H. Cansever and *J. Lindner* from the Institute of Ion Beam Physics and Materials Research in Dresden (Germany), ref. [3], consider the use of microresonators and microantennas as a tool for the study of magnetization dynamics in single magnetic nanostructures. The study of single element nanostructures is a complex problem due to the reduced magnetic signals that are available. To enhance the detection of single magnetic elements, the authors have used a microcavity and microresonator planar structures to detect the ferromagnetic resonance (FMR) signals of these elements. Fixed frequency cavities and broadband measurements of permalloy ($Ni_{80}Fe_{20}$) and $Fe_{60}Al_{40}$ microstrips demonstrate the excellent signal-to-noise obtained using these methods.

The contribution by *R. Yadav, C.-H. Wu, I-Fen Huang and K.-W. Lin* from the National Chung Hsing University (Taiwan), *X. Li* from Xiamen University (China) and *T.-H Wu* from the National Yunlin University of Science and Technology (Taiwan), ref. [4], describe the effects of a perpendicular magnetic field annealing on the structural and magnetic properties of $[Co/Ni]_2$/PtMn thin films. In this study the authors use a post-deposition perpendicular magnetic field annealing process which induces interlayer diffusion at both the Co and Ni interfaces as well as that with the PtMn layer. Structural and magnetic characterization were studied using TEM, XPS and VSM techniques.

The study of the control of spin dynamics in weak perpendicular magnetic anisotropy (PMA) systems is the subject of the contribution by *L. M. Álvarez-Prado* from the Center of Research on Nanomaterials and Nanotechnology and the University of Oviedo (Spain), ref. [5]. In this work, the formation of weak magnetic stripe domains is achieved due to the PMA of a $NdCo_5$ layer coupled to a soft permalloy film via an intervening Al spacer. By varying the thickness of this spacer layer it is possible to control the coupling and hence the overall properties of the composite magnetic structure. The resulting imprinting of the stripe domain structure has been simulated along with the FMR properties of these hybrid systems, which show a non-reciprocal response with respect to the stripe domain regions and the applied magnetic field. The study further considers the nature of the reconfigurability of these magnetic structures.

The final contribution to this special issue considers aspects of ferromagnetic resonance in the study of magnetic nanosystems by *D. S. Schmool* and *D. Markó* from the University Paris-Saclay/University of Versailles Saint-Quentin-en-Yvelines (France), *K.-W. Lin* from the National Chung Hsing University (Taiwan), *A. Hierro-Rodríguez, C. Quiróz, J. Díaz* and *L. M. Álvarez-Prado* from the Center of Research on Nanomaterials and Nanotechnology and the University of Oviedo (Spain) and *J.-C . Wu* from the National Changhua University of Education (Taiwan), ref. [6]. In this paper the authors present the broadband VNA-FMR technique which has been applied to the study of periodic Co/Ag bilayer nanostructures as well as to the multilayer system comprised of NdCo/Al/permalloy films. In the former system the modification of the FMR spectra of the nanodot structures with respect to continuous layers is illustrated, showing the variation of pinning parameters and the emergence of a localized resonance. In the latter system, the low-field/low-frequency response of the FMR is studied in detail, illustration the effect of domain structures and the hysteresis in the dynamic measurements, which can be correlated to static hysteresis in these layers. The switch between acoustic and optical excitation allows the evaluation of the periodicity of the domain structures to be performed and shows excellent agreement with static measurements.

I hope that this Special Issue on *Recent Advances in Nanomagnetism* will provide some useful insights into this rapidly developing area of current research in to magnetism and magnetic materials. I would like to thank all the authors who contributed to this Special Issue for their work and the high standard of their contributions. I finally wish to acknowledge the assistance and dedication of the editorial staff of *Magnetochemistry*, who have greatly assisted me in the preparation of this Special Issue.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

FMR	Ferromagnetic resonance
PMA	Perpendicular magnetic anisotropy
TEM	Transmission electron microscopy
VNA	Vector network analyzer
VSM	Vibrating sample magnetometry
XPS	X-ray photoelectron spectroscopy

References

1. Ziogas, P.; Bourlinos, A.B.; Tucek, J.; Malina, O.; Douvalis, A.P. Novel Magnetic Nanohybrids: From Iron Oxide to Iron Carbide Nanoparticles Grown on Nanodiamonds. *Magnetochemistry* **2020**, *6*, 73. [CrossRef]
2. Pathak, S.A.; Hertel, R. Geometrically Constrained Skyrmions. *Magnetochemistry* **2021**, *7*, 26. [CrossRef]
3. Cansever, H.; Lindner, J. Microresonators and Microantennas - Tools to Explore Magnetization Dynamics in Single Nanostructures. *Magnetochemistry* **2021**, *7*, 28. [CrossRef]
4. Yadav, R.; Wu, C.-H.; Huang, I.-F.; Li, X.; Wu, T.-H.; Lin, K.-W. Effects of Perpendicular Magnetic Field Annealing on the Structural and Magnetic Properties of [Co/Ni]2/PtMn Thin Films. *Magnetochemistry* **2021**, *7*, 38. [CrossRef]
5. Álvarez-Prado, L.M. Control of Dynamics in Weak PMA Magnets. *Magnetochemistry* **2021**, *7*, 43. [CrossRef]
6. Schmool, D.S.; Markó, D., Lin, K.-W.; Hierro-Rodríguez, A.; Quirós, C.; Díaz, J.; Álvarez-Prado, L.M.; Wu, J.-C; Ferromagnetic Resonance Studies in Magnetic Nanosystems. *Magnetochemistry* **2021**, *7*, 126. [CrossRef]