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EDITORIAL

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Varun Chaudhary[1], R Nirmala[2] and Yulong Huang[3,4]

[1] Industrial and Materials Science, Chalmers University of Technology, SE-41296 Gothenburg, Sweden
[2] Department of Physics, Indian Institute of Technology Madras, Chennai 600 036, India
[3] Shared Instrumentation Laboratories, University at Buffalo, The State University of New York, Buffalo, NY, 14260, United States of America
[4] Department of Chemical and Biological Engineering, University at Buffalo, The State University of New York, Buffalo, NY, 14260, United States of America

E-mail: varunc@chalmers.se

Abstract

Magnetic materials are omnipresent in everyday life, with applications spanning a wide range of fields. This focus collection provides a comprehensive overview of recent developments in the synthesis and characterization of advanced magnetic materials, both in their bulk and low-dimensional forms. These studies aim to enhance our understanding of fundamental physical properties and identify suitable candidate materials for various device applications. We believe that this focus collection will serve not only as a valuable reference but also as a source of inspiration for further research on advanced magnetic materials.

Magnetic materials play a vital role in modern technology with their potential applications in energy, healthcare, electronics, communication, thermal management, etc. These materials are integral to devices like electric motors, transformers, magnetic sensors, data storage systems, magnetocaloric devices and medical imaging technologies [1–6]. With the advent of advanced manufacturing techniques and computational modeling, magnetic materials have expanded their relevance to emerging fields like spintronics, quantum computing, and sustainable energy systems [7–10]. The global market for magnetic materials is poised for sustained growth, driven by increasing demand for renewable energy solutions, miniaturized electronics, and advanced healthcare devices. This rapid development necessitates a deeper understanding of the synthesis, properties, and applications of magnetic materials to unlock their full potential in existing and novel applications.

The papers included in this issue 'Magnetic Materials and Devices' contribute significantly to this endeavor by addressing various aspects of magnetic materials, devices and their applications. One key area of interest is Heusler alloys, known for their diverse properties and wide range of potential applications. Studies on V_2MnAs and V_2MnGa show their stability and promising thermoelectric performance, with large Seebeck coefficients [11]. In contrast, investigations into the quaternary Heusler alloys LiXNiSb (X = Be, Mg, Ca, Sr, Ba) show that while these alloys crystallize in type-III arrangements, they lack a resultant magnetic moment despite the presence of magnetic Ni [12]. Among the studied alloys, LiMgNiSb is metallic, while LiCaNiSb and LiSrNiSb are semiconducting, with the latter two showing promise for solar cell applications due to their significant absorption in the visible spectrum. Together, these findings underscore the versatility of Heusler alloys in energy technologies.

Magnetic fields play a significant role in influencing the thermoelectric properties of metal-oxide based systems. Notably, phenomena such as the spin Seebeck effect and the anomalous Nernst effect are critical in the functioning of thermoelectric devices. Understanding how magnetism induces unconventional thermoelectric responses is essential for the development of efficient energy conversion technologies. The review by Dubey *et al* explored the impact of magnetic fields on the thermoelectric properties of metal oxides, emphasizing their potential for enhancing energy conversion efficiency through improved Seebeck coefficients, thermal conductivity, and electrical resistivity [13].

In the field of energy conversion, the performance of electric machines is highly dependent on both soft magnetic materials and permanent magnets (PM). With the depletion of rare-earth elements and the rising costs and instability of their supply, there is an increasing demand for rare-earth-lean or rare-earth-free PMs. In response, Li *et al* focused on optimizing the ball milling process to achieve high maximum energy product $(BH)_{max}$ values for the rare-earth-free PM, MnBi, in its low-temperature phase [14]. On the other hand, Karabulut *et al* have manufactured stator cores of soft magnetic composite material and grain-oriented steel for small-size axial flux permanent-magnet synchronous machines. Their analysis concluded that grain-oriented steel outperforms other materials in terms of lower iron loss, torque, and efficiency [15]. Nunez *et al* utilized high energy X-ray irradiation to modify magnetocaloric materials $(MnNiSi)_{1-x}(Fe_2Ge)_x$ and $LaFe_{13\text{-x-y}}Mn_xSi_yH_z$ for the investigation of magnetic cooling application [16]. With sustained crystal structures and magnetic phases under irradiation, the change in maximum magnetic entropy shifts to different temperatures in two materials. The enhanced magnetization also provides the potential for an advanced technology in magnetocaloric energy conversion.

The understanding of magnetic structure lays a solid foundation for facilitating the technological application of room-temperature magnetic materials [17]. Banerjee *et al* studied magnetic properties of an antiferromagnetic compound $LiFe_2SbO_6$ from 2 K to 900 K, which exhibit high-temperature magnetic order with a collinear spin structure and magnetodielectric coupling at a much lower temperature than magnetic ordering [18]. In such scenario, a negative magnetocapacitance arises at a low-temperature magnetic phase crossover point, which is revealed by neutron powder diffraction, DC magnetization and specific heat measurements. Guzman *et al* prepared thin films of Ni-Zn ferrites using the magnetron sputtering technique, and studies the magnetic properties, metal valence states and ferromagnetic resonance, showing the potential application on high-frequency devices [19].

Additive manufacturing (AM) has emerged as a promising approach for producing complex, net-shaped components with minimal waste, and has recently been employed in the development of novel magnetic materials [7, 20]. Sharma *et al* explored the potential of utilizing AM to print magnetocaloric materials suitable for heat-exchange structures [21]. They have created structures of lanthanum-calcium based manganite oxide particles and studied their magnetocaloric properties to assess the technical feasibility of employing AM for magnetic heat pumps. As we look to the future of data storage and logic devices, skyrmions have garnered significant attention due to their potential applications in spintronics. These topological structures can significantly impact magnetic data storage technologies. Mohanty *et al* observed topological Hall effect and skyrmions in the multilayer system, Pt/Co/Ir/Co/Pt by tuning the spacer layer thickness, using combined transport and magnetic force microscopy studies [22].

At the nanoscale, anisotropic magnetite nanoparticles exhibit distinct magnetic and electronic properties, which can be finely tuned by factors such as size, shape, and composition [23, 24]. Various synthesis techniques, including thermal decomposition and co-precipitation, enable precise control over nanoparticle size and shape, facilitating tailored magnetic properties [25]. The shape and magnetocrystalline anisotropy of Fe_3O_4 nanoparticles also play crucial roles in defining their magnetic attributes, with different geometries leading to varied saturation magnetization and coercivity values. These nanoparticles hold considerable potential in fields like spintronics and magnetic resonance imaging, where optimized magnetic properties are essential for enhanced performance. Mitra *et al* reviewed the role of magnetic anisotropies on magnetic and magnetoresistance properties at the nanoscale, showcasing how surface, shape, and magnetocrystalline anisotropies can be engineered to achieve precise control of magnetic behavior [26]. Fan *et al* developed the doping of holmium into Y-Fe-B based permanent magnets for the enhancements of magnetic properties and thermal stability. Besides, a hot-pressing and hot deformation process significantly improves the intrinsic coercivity [27].

Activated carbon is well-known for its high surface area, excellent chemical stability, and versatility, making it an ideal material for various applications, including adsorption, catalysis, and electrochemical processes. Its use in electrochemistry, in particular, has garnered significant attention due to its ability to enhance sensor performance. Building on these properties, a nanocomposite of nickel ferrite and activated carbon (NiF/AC) was developed to improve a highly sensitive electrochemical sensor for detecting theophylline (TPL) in pharmaceutical tablets [28]. Khatun *et al* optimized the composition to stabilize the desired ferromagnetic properties in iron and nickel co-doped tin oxide nanoparticles [29]. This advancement highlights the growing role of magnetic materials in healthcare, particularly in enhancing diagnostic tools.

The articles in this Focus Issue offer a comprehensive insight into the expanding field of magnetic materials and devices. We hope that this collection will inspire continued research and development in this critical area of science and its applications.

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Data availability statement

No new data were created or analysed in this study.

ORCID iDs

Varun Chaudhary https://orcid.org/0000-0002-9244-1975
R Nirmala https://orcid.org/0000-0001-6292-8769

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