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Editorial

Advances in Metal-Containing Magnetic Materials and Magnetic Technologies

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1. Introduction

Magnetic materials generally refer to materials with ferromagnetic or ferrimagnetic ordering. In a broad sense, they also include weak magnetic and antiferromagnetic materials which can provide magnetism and a magnetic effect. Most magnetic materials contain metallic elements with 3d and/or 4f electrons, and they exhibit strong magnetism or significant interactions between magnetism and other physical properties.

Magnetic materials have found increasing applications in various fields, including electric motors, mechanical equipment, electronic devices, information recording, sensors, etc. The development of intelligent equipment, AI, 5G, consumer electronics, biomedicine, aerospace technology, and the military industry has created higher requirements for various types of magnetic materials. Since the previous century, traditional magnetic materials such as permanent magnets and soft magnets have seen innovations in their composition, structure, and processing. Advanced magnetic materials are continuously emerging. Concepts for new technologies are also under quick development.

This Special Issue entitled "Advances in Metal-Containing Magnetic Materials" has collected 11 manuscripts from a broad field of research. The topics addressed in this Special Issue include permanent magnets, soft magnets, magnetocaloric materials, magnetostrictive materials, magnetic thin films, and magnetic technologies. Nine research papers and two review papers provide the recent progress in magnetic materials and technology that has been made in the following institutes: South China University, the Guangdong Academy of Sciences, Southwest Minzu University, the University of Electronic Science and Technology of China, the University of Science and Technology Beijing, and the Beijing Institute of Spacecraft Environment Engineering. These articles are attractive for scholars in these fields.

2. Contributions

Two papers on permanent magnets are presented in this issue. He et al. [1] reviewed sources of grain boundary diffusion (GBD) and their coating methods for Nd-Fe-B permanent magnets. The GBD process, which is one of the most exciting technologies for rare earth permanent magnets that has emerged in this century, provides the best route for fabricating highly coercive Nd-Fe-B magnets with low levels of consumption of expensive HRE resources. Differing from previous review articles regarding GBD, this review provides an introduction of the typical types of diffusion sources and their fabrication approaches. The effects of the diffusion source on the microstructure and magnetic properties of magnets are summarized. In particular, the principles and applicability of different coating approaches ae discussed in detail. It is believed that this review can provide technical guidance for designing the diffusion process and products meeting specific requirements. Xiao et al. [2] report the effects of partially substituting the element Holmium (Ho) on the magnetic properties and microstructure of nanocrystalline melt-spun Nd-Fe-B alloys with a composition of $[(NdPr)_{1-x}Ho_x]_{14.3}Fe_{76.9}B_{5.9}M_{2.9}$ (M = Co, Cu, Al and Ga). They show that Ho can significantly enhance the coercivity (H_{cj}) and elevate the temperature behavior of

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the remanence (M_r) and the thermal stability. Their finding provides an important reference for the efficient improvement of the thermal stability of Nd-Fe-B-type materials.

Four papers focus on soft magnets. Li et al. [3] investigated the soft magnetic properties of the melt-spun, high-entropy alloys (HEAs) $Fe_{27}Co_{27}Ni_{27}Si_{10-x}B_9La_x$. They obtained superior soft magnetic properties with a low level of coercivity H_c of ~7.1 A/m and a high saturation magnetization B_s value of 1.07 T in an $Fe_{27}Co_{27}Ni_{27}Si_{9.4}B_9La_{0.6}$ alloy. They also found that the content of La has an important effect on the primary crystallization temperature and the secondary crystallization temperature of the alloys. Yu et al. [4] prepared Fe-based amorphous magnetic cores (AMPCs) from FeSiBCr amorphous powders with phosphate–resin hybrid coatings. The high-frequency magnetic properties of AMPCs annealed at different temperatures were systematically studied. The annealed sample exhibited the lowest hysteresis loss of about 29.6 mW/cm^3 at 800 kHz, as well as a maximum effective permeability of 36.4, which could be used in high-frequency applications of up to 3 MHz. Luo et al. [5] prepared core–shell-structured amorphous FeSiBCr@phosphate/silica powders and soft magnetic composites (SMCs) via phosphation and a sodium silicate treatment. By optimized the phosphating process, a uniform and dense insulation layer can be formed on the powder surface, which is beneficial for the subsequent coating of sodium silicate. By optimizing the sodium silicate treatment, a complete and uniform SiO_2 layer can be formed well on the phosphated powders, leading to a double-layer core—shell structure and excellent soft magnetic properties. The SMCs exhibited excellent soft magnetic properties with a permeability value of μ_e = 35 and a core loss of P_s = 368 kW/m^3 at 50 mT/200 kHz. Xie et al. [6] fabricated FeSiCr SMCs via the sol–gel method, and an Al_2O_3/resin composite layer was employed as insulation coating; this not only effectively reduced the core loss, increased the resistivity, and improved the quality factor but also increased the thermal conductivity of the SMCs. A high thermal conductivity is beneficial to enhancing the high-temperature performance, lifetime, and reliability of SMCs.

Magnetocaloric and magnetostrictive materials have also attracted significant attention. Zhong et al. [7] prepared magnetocaloric La(Fe,Si)$_{13}$/Ce-Co composites via a one-step sintering process. Using 15 wt.% Ce_2Co_7 as a dopant and binder, the Curie temperature (T_C) increased from 212 K to 331 K, and the change in the maximum magnetic entropy $(-\Delta S_M)_{max}$ decreased from 8.8 to 6.0 J/kg·K under a 5 T field. High values of compressive strength of up to 450 MPa and high thermal conductivity values of up to 7.5 W/m·K were obtained. Their work demonstrates that the one-step sintering process is a feasible route to producing La(Fe,Si)$_{13}$-based magnetocaloric composites with large MCE values, good mechanical properties, attractive thermal conductivities, and tunable T_C values. Yang et al. [8] reviewed the recent advances in magnetostrictive Tb-Dy-Fe alloys. They began with a brief introduction to the characteristics of Tb-Dy-Fe alloys and then focused on the research progress in recent years, including improved processes such as directional solidification, the magnetic field-assisted process, ferromagnetic MPB theory and sensor applications, and the reconstruction of the grain boundary phase for sintered composite materials. This review will be helpful for the design of novel magnetostrictive Tb-Dy-Fe alloys with improved properties.

He et al. [9] carried out a quantitative study of the surface composition of a NiFe thin film exposed to atmospheric conditions via angle-resolved X-ray photoelectron spectroscopy (ARXPS). The coexistence of metallic and oxidized species on the surface was demonstrated. The thicknesses of the oxidized species, including NiO, $Ni(OH)_2$, Fe_2O_3, and Fe_3O_4, were also estimated. This work provides an effective approach to clarifying the surface composition and demonstrated the dependence between the magnetic properties and thicknesses of NiFe thin films.

Fluxgate magnetometers are commonly used to detect weak magnetic targets, but the detection accuracy of a fluxgate magnetometer is affected by its own error. To obtain more accurate detection data, the sensor must be error-corrected prior to its application. Previous researchers easily fell into the local minimum when solving error parameters. In a paper by Li et al. [10], an error correction method is proposed to tackle the problem;

this method combines the dragonfly algorithm (DA) and the Levenberg–Marquardt (LM) algorithm, thereby solving the problem of the LM algorithm and improving the accuracy of solving the error parameters. The simulation results show that the DA–LM algorithm can accurately solve the error parameters of the triaxial magnetic sensor, and the difference between the corrected and the ideal total value was decreased from 300 nT to 5 nT.

Due to the complex environment of the ocean, underwater equipment has become a very threatening means of surprise attack in modern warfare. The timely and effective detection of underwater moving targets is the key to obtaining warfare advantages and has important strategic significance for national security. Xu et al. [11] proposed a moving target detection method based on magnetic flux induction technology. Their results showed their technology has an obvious response to moving targets and can effectively capture target signals.

3. Conclusions and Outlook

This Special Issue focuses on the preparation, microstructure, and properties of various metal-containing magnetic materials, including hard magnetic materials, soft magnetic materials, magnetocaloric materials, magnetostrictive materials, magnetic thin films, and magnetic technologies. Some advanced approaches to producing and synthesizing hard magnetic and soft magnetic materials and magnetic refrigeration materials are described. The surface characterization of magnetic thin films is proposed. In addition, we also accepted contributions which focused on magnetic technologies with reduced errors or improved detection. The main goal of this Special Issue to describe the most recent advances in strong magnetic materials and emerged magnetic technologies has been fulfilled.

Hard and soft magnets are the fundamental materials for electrical and electronic devices and will be constantly developed with the aim of achieving high levels of performance, small sizes, and low costs with the help of new concepts and new technologies. Other magnetic materials based on the interactions between magnetic properties and other properties, such as thermal, electric, optical, and mechanical properties, have attracted and will attract more attention in the future.

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