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Editorial

Advancing sustainability: Magnesium-based solutions for environmental challenges and high-performance technologies in superconductivity

The Journal of Magnesium and Alloys (JMA) is actively dedicated to addressing crucial issues related to energy conservation, emission reduction, energy crises, and sustainable development [1]. Magnesium, recognized as the lightest commercial structural metal and a promising energy storage material, holds immense potential in contributing to strategic objectives such as achieving "carbon neutrality" and the "emission peak", thus mitigating the ongoing energy crisis [2]. JMA diligently reports on various research fronts, including magnesium-based structural materials, magnesium batteries, magnesium-based hydrogen storage materials, and magnesium-based superconducting super magnets [3].

In the context of these advancements, it becomes increasingly evident that innovative solutions are imperative due to the severe consequences of climate change and global warming, primarily driven by the continued use of fossil fuels. The excessive emission of carbon dioxide has resulted in a substantial rise in the global average temperature, anticipated to surpass the 1.5 °C limit stipulated by the Paris Agreement by 2040 [4]. Alarming levels of CO_2 and methane, exceeding pre-industrial levels, have been reported by the World Meteorological Organization.

Despite a marginal decline in emissions during the COVID-19 pandemic, it had negligible effects on greenhouse gas concentrations. Recent events, such as the potential ice shelf breakage in Antarctica's Thwaites Glacier due to warming ocean water, underscore the imminent risk of rising sea levels. The melting of Thwaites Glacier alone could lead to a 2–3 feet rise, and when combined with other glaciers, the impact could be up to 10 feet, posing significant threats to coastlines, populations, and ecosystems [5]. The exploration of magnesium-based solutions, as highlighted by JMA, becomes increasingly crucial in the broader context of addressing and mitigating the environmental challenges posed by climate change.

To address these issues, a shift towards green energy and sustainable technologies is crucial. Renewable energies such as solar, wind, geohydro, and batteries, along with technologies that reduce greenhouse gas emissions, are essential [6]. The need for intensified efforts and cutting-edge technologies is crucial for the future of the world [7]. Recent advancements include superconducting devices like flywheel energy storage, fusion energy, and superconducting magnetic energy systems. These technologies offer promising solutions for clean energy, with projects like SPARC, ITER, and Tokamak nearing realization [8–11].

Recent advancements have elucidated the development of ultra-lightweight and high-performance superconductor wires tailored for constructing lightweight superconducting cables [12,13]. These cables enable the efficient transfer of renewable energy over long distances, particularly from hot deserts or climates [14]. While superconducting technology holds great potential, concerns about installation and maintenance costs persist. Scientists are developing cost-effective solutions, such as magnesium-based compound MgB_2 superconductors [15], to make these technologies more accessible for various industrial applications [16,17].

The increasing demand for cost-effective and high-performance MgB_2 superconductors is driven by the helium shortage crisis [15]. MgB_2, an advanced high T_c superconductor, not only delivers outstanding performance but also eliminates the reliance on helium cryogenics [18,19], although it requires lower temperatures compared to some other high-temperature superconductors [20]. Through the innovative application of the Gaussian Process Regression (GPR) model, significant progress has been achieved in comprehending the interplay between lattice parameters and the superconducting transition temperature of disordered MgB_2 superconductors. This exploration has predicted a superconducting transition temperature of 56 K [21]. Despite this temperature limitation, MgB_2 offers numerous advantages, including a streamlined fabrication process, more affordable base materials, and robust superconducting parameters, making it an ideal choice for various industrial applications [19].

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What makes MgB_2 particularly attractive is its application in bulk magnets, commonly referred to as “super-magnets” [22–24]. These super-magnets find extensive use in MRI coils and nuclear magnetic resonance (NMR), non-contact bearings for liquid pumping, wind generators, fault current limiters, and magnetic shielding screens, a new class of drug delivery systems [15,16,19]. Moreover, MgB_2 is positioned to play a crucial role in advancing superconducting cables for the next generation of DC power transmission in solar and wind energy networks. This is particularly vital for transferring energy from distant production facilities to end-user applications with minimal loss [25,26]. In this context, MgB_2 superconducting joining technology holds significant importance [27,28]. The key requisites for these diverse applications are high critical current densities and top-notch materials, setting the stage for the mass production of MgB_2 magnets and power cables to meet the escalating demands of modern technology.

Considerable efforts have been invested in enhancing the critical current density (J_c) and flux pinning properties of MgB_2. This has been achieved through the introduction of various dopants such as NaCl, Al, Sc, Zn, MgGa, GeO_2, Se, Rh, Ag, In, Sb_2O_3, SiC, Te, Eu, Pt, Bi, MgO, Cu, various carbon sources, MgB_4, Dy_2O_3, rare-earth elements, and their respective oxides [19,21,29–40]. This widely adopted technique involves creating lattice disturbances via substitutions, strains, and defects to serve as effective flux pinning sources, particularly under high magnetic fields. Notably, it has been revealed that carbon-coating nano boron as a dopant leads to a more homogeneous material [41].

Simultaneously, diverse production methods have been explored for MgB_2 powders and bulks, with a focus on structural modifications through manipulating precursor characteristics (amorphousness and crystallinity), purity, and particle size, emphasizing grain boundary pinning [19]. Nano-sized boron powder, initially introduced into the process, has emerged as the most suitable option, yielding high-performance MgB_2 with exceptional properties, where grain boundaries will act as flux-pinning centers. However, the cost-effectiveness and performance are contingent on the production of these nano boron powders [19]. Alternatively, techniques such as ball-milling and paralysis methods have been employed to enhance material purity and reduce costs, respectively. The ultrasonication process has also been successfully utilized, with optimization of power, time, and temperature parameters, using ultrasonic media as a cost-effective alternative to produce nano boron [19,42]. These collective efforts have effectively decreased the nano boron size from micrometer to nano order, instilling optimism for the production of magnesium-based super magnets and superconducting cables across laboratory and industrial sectors.

Current endeavors and recent advancements indicate that the realization of low-cost, high-performance superconducting cables and cryo-magnets is imminent. This development holds significant promise for applications in the medical, transportation, space, power industry, and research fields, contributing to the overall sustainability of various sectors. Moreover, these technologies play a pivotal role in substantially decreasing waste and present the opportunity to address the pressing global issues of CO_2 emissions reduction and energy conservation.

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