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論　文　要　旨
Thesis Abstract

(yyyy/mm/dd) 2024 年　09 月　02 日

※報告番号	甲第 354　号	氏　名 (Name)	MALIK SHADAB

主論文題名　（Title）

Advancing Bulk MgB_2 Superconductors: Innovative Techniques for Economical Production, Enhanced Grain Connectivity, and the Influence of Varied Boron Sources and Machining Precision

内容の要旨　（Abstract）

Since 2001, Magnesium diboride (MgB_2) has been a pioneering high-critical temperature superconductor with a transition temperature ($T_{c,\ onset}$) of 39 K. Its versatility in forms such as bulk materials, thin films, tapes, and wires makes it suitable for applications like motors, superconducting cables, particle accelerators, and flywheel storage. Its high T_c, cost-effectiveness, and lightweight properties make it attractive for practical use, especially in high magnetic field environments, maintaining its significance in the superconductivity community.

This thesis aims to enhance the critical current density (J_c) in polycrystalline bulk MgB_2 for cost-effective, lightweight superconducting devices. While MgB_2 thin films exhibit high J_c (10^4 to 10^5 kA/cm^2) and H_{c2} up to 60 Tesla near 0 K, bulk MgB_2 lacks these properties due to inadequate flux pinning and poor grain connectivity. Large grain size differences between magnesium and boron cause voids, reducing density. Conventional sintering methods produce good crystallinity but poor flux pinning and defects, lowering J_c. This study fabricates bulk MgB_2 via solid-state sintering at 775 °C for 3 hours, emphasizing control over boron particle size to optimize J_c.

Due to the challenges of magnesium's high volatility and tendency to oxidation, we focus on machining boron to increase grain boundaries. We use three types of boron powders: nano size amorphous boron, crystalline boron, and amorphous boron. Fully crystalline boron is refined by ball milling, while amorphous boron is refined by ball milling and ultrasonication. We explored techniques to enhance the superconducting properties of bulk MgB_2 using different boron powders. Using commercial nano-amorphous boron, we achieved a self-field J_c of 362 kA/cm^2 at 20 K via solid-state sintering. FE-SEM confirmed nano-sized grains in the final MgB_2 samples.

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内容の要旨(Abstract)

Crystalline boron powder, processed via ball milling and sieving, achieved outstanding J_c values at 10 K under various magnetic fields. Co-doping with 4.5 wt.% silver (Ag) further improved J_c. SEM analysis confirmed secondary nano Ag-Mg phases (20-40 nm) as effective pinning centers along with primary grain boundary pinning. Spark Plasma Sintering (SPS) improved density by reducing porosity, achieving 97% of the theoretical value for MgB_2. SPS samples showed high critical current densities (J_c), reaching 2.61×10^5 A/cm^2 in self-field at 20 K, a 67% improvement over solid-state sintering.

Utilizing the Taguchi L_9 experiments optimized high-energy ball milling for amorphous boron, doubling the critical current density in sintered bulk MgB_2. FE-SEM showed refined boron morphology, and XRD confirmed the desired MgB_2 phase with low impurities. Optimal parameters for ball milling (400 rpm, 3 hours, 5:1 ball-powder ratio) enhanced J_c to 398 kA/cm^2 at 20 K.

Furthermore, we explored ultrasonication refinement techniques, resulting in significant improvements in critical current density. Ultrasonication in 2-Propanol and 1-Heptanol mediums produced finely powdered boron, with the latter medium yielding the highest improvement in self-field J_c, reaching approximately 0.6 MA/cm^2 at 10 K and 417 kA/cm^2 at 20 K, nearly doubling the improvement compared to regular bulk MgB_2.

Our efforts highlight the effectiveness of various refinement techniques in enhancing the superconducting properties of bulk MgB_2 using different boron precursors, thereby advancing superconductivity applications. Input parameters such as rotational speed, duration, ball-powder ratio, ultrasonication power, time, and solvent choice significantly impact machining costs and output. Optimizing these parameters boosts manufacturing competitiveness. This thesis systematically optimizes machining parameters to improve superconducting properties.

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