Fabrication of superconductive muscovite via MgB_2 intercalation

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Abstract: Muscovite, a naturally flexible layered clay mineral, offers an ideal platform for intercalation due to its expansive lateral dimensions and compact interlayer spaces. This study primarily explored the intercalation of magnesium diboride (MgB_2) into muscovite, aiming to adjust its superconducting critical temperature (Tc) with a simple strategy. Employing techniques such as X-ray diffraction (XRD) and electron microscopies, we confirmed the successful intercalation and analyzed the structure and morphology of the MgB_2-muscovite composite. Notably, MgB_2, with a Tc of around 39K, has given rise to significant interest due to its distinctive superconducting properties and potential in various technological applications. Our research demonstrated the ability to modulate the critical temperature of the composite material using a bending stage, with the advantage of muscovite's flexibility. External strain, estimated at 5.9 GPa, caused the Tc to decline from 36K to 34.7K, but it reverted upon pressure release. This novel composite material and approach manipulated superconductivity via intercalation. It offers insights into the intriguing properties and hints at potential applications in superconducting devices and fundamental physics.

Keywords: Intercalation, Superconductivity, muscovite, MgB_2, Alterable Critical Temperature

1. Introduction

Muscovite, a flexible and natural layered clay mineral with vast lateral dimensions and interlayer spaces in a compact volume, serves as an ideal platform for intercalation. The interlayers of muscovite covalently bond atomic lattices via weak van der Waals interactions. Various foreign species can be inserted within these interactions through intercalation processes without disrupting the in-plane covalent bonds. The intercalated composite material retains extensive tunable physical and chemical properties, offering unprecedented opportunities for fundamental property modulation studies. The potential applications of this material span multiple technologies, including electronics, optics, superconductors, thermoelectrics, catalysis, and energy storage.

Magnesium diboride (MgB_2) displays superconductivity with a critical temperature (Tc) of approximately 39K. The emergence of superconducting properties in MgB_2 has captured significant attention. Compared to traditional low-temperature superconductors, its straightforward crystal structure, considerable coherence lengths, high critical current densities and fields, and grain boundary transparency to current, make it a potential candidate for various applications, especially in superconducting devices. External strain can influence its superconductivity due to shifts in the electronic structure and the material's crystal lattice. Notably, the Tc of MgB_2 decreases when external pressure is applied, a behavior diverging from many other superconductors. These distinctive properties have catalyzed numerous related studies, with much focus on MgB_2 fundamental research. Researchers continue to develop mechanisms explaining the superconductivity in MgB_2 and explore more possibilities to modify its properties.

2. Technical Work

In our study, we successfully intercalated MgB_2 into muscovite and altered the Tc by introducing a simple strategy to create an external strain. Employing techniques such as X-ray diffraction (XRD), scanning electron microscope (SEM), transmission electron microscopy (TEM), atomic force microscope (AFM), optical microscope (OM), and field emission-electron probe micro-analyzer (FE-EPMA), we investigated the crystal structure and morphology of the MgB_2-muscovite composite material (muscovite/MgB_2). Additionally, we analyzed the temperature dependence of the magnetic moment of muscovite/MgB_2 using a physical property measurement system-vibrating sample magnetometer (PPMS-VSM).

We first prepared muscovite/MgB_2 through high-temperature annealing in a vacuum furnace. We then exfoliated the uppermost layer of muscovite/MgB_2 to ensure all derived properties resulted from the intercalated MgB_2. XRD confirmed the successful intercalation, and we observed the morphology of intercalated MgB_2 through SEM, TEM, OM, AFM, and FE-EPMA. The measured critical temperature via PPMS-VSM aligned with previously reported references. Furthermore, with the advantages of flexibility of muscovite, we designed a method to bend muscovite/MgB_2, enabling modulation of the critical temperature through applied strain. As observed, the Tc declined from 36K to 34.7K under external pressure and reverted to 36K upon pressure release. In our experiments, the external strain was estimated at 5.9 GPa, consistent with results from traditional diamond anvil cell experiments.

We've crafted a novel composite material feature with superconductivity by appropriately intercalating MgB_2 into muscovite. We also demonstrated the ability to alter and restore the critical temperature of MgB_2 using a simple bending strategy. Our ongoing research on this muscovite/MgB_2 layered structure aims to discover more profound insights into this fascinating composite. We aspire to pioneer a new avenue in understanding the fundamental physics and potential applications of muscovite intercalation, starting from an excellent example of intercalated MgB_2.

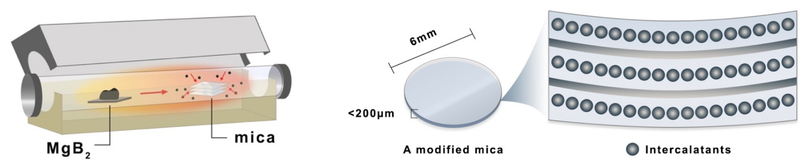

Fig. 1. Scheme of Intercalation

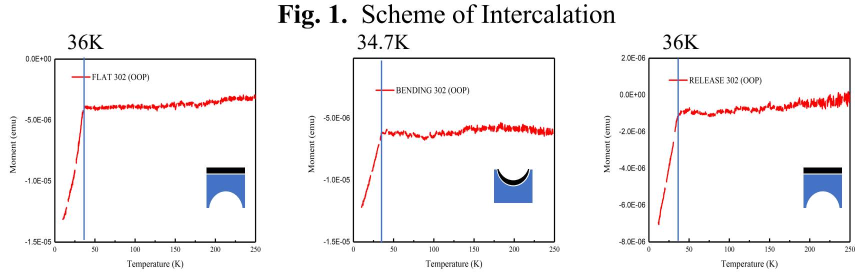

Fig. 2. Temperature dependence of magnetic moment of muscovite/MgB_2 under external strain by bending (a) without external strain, (b) applied external strain, and (c) released from external strain.

3. Conclusions

In this comprehensive exploration, we successfully intercalated Magnesium diboride (MgB_2) into muscovite, a naturally flexible layered clay mineral, aiming to manipulate its superconducting properties. Muscovite's inherent flexibility and structural characteristics were pivotal in creating a composite material with adjustable superconducting critical temperatures (Tc). Using a simple bending strategy, we demonstrated the modulation of the Tc, a decline from 36K to 34.7K as shown under applied external strain and its subsequent reversion upon pressure release. An external stress of 5.9 GPa was estimated in our design, which aligns with results from traditional diamond anvil cell methods, underscoring the efficacy of our approach. Our findings not only enrich the understanding of superconducting properties in muscovite/MgB_2 composites but also pave the way for future technological applications, particularly in superconducting devices. Moreover, the study's outcomes highlight the vast potential of muscovite intercalation, hinting at its broader fundamental studies. Our research opens exciting avenues in superconductivity manipulation and offers an example for further investigations into the intercalation of layered composite materials.

References

[1] J. Zhou, Z.et al., Adv. Mater. 33, 2004557 (2021).
[2] C. Buzea, et al., Sci. Technol. 14, R115 (2001).
[3] Nagamatsu, J., et al., Nature 410, 63–64 (2001).